ELECTRICAL ENGINEERING

AUGUST 1945

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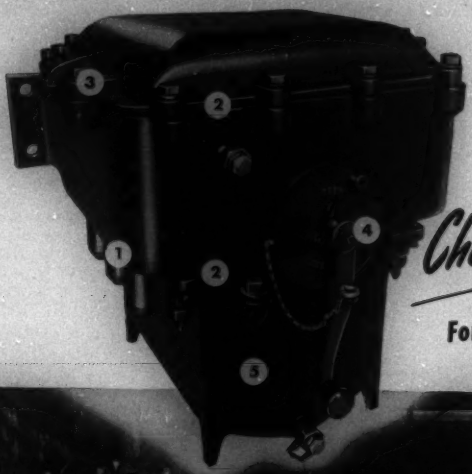

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For Safe Underwater Operation

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4. HANDLE OIL SEAL
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● **The watertight features of the Roller-Smith MS2 Subway Switch permit installation of a switch in the manhole so that it can operate safely even when completely submerged. A whole underground distribution system could be under water and the switches could be operated with safety.**

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FORMULATED strictly in keeping with the JOHN C. DOLPH COMPANY'S policy of high quality insulating varnishes and compounds, SYNTHITE # 924-20 Clear Air-Drying Varnish has added "new Laurels" to the already proven and tested DOLPH Line. . . . The following features, each one of a high degree, have been combined in SYNTHITE # 924-20 to give you the best performance possible in a varnish of this type.

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* **SYNTHITE # 924-20** may be applied by either dipping, brushing or spraying, this to be governed by your own specific application. It will air dry on flat surfaces in 2 to 3 hours, but may be forced dried if time is an important factor.

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Fiberglas* Tying Cord puts the finishing touch on a quality Job

Fiberglas Tying Cords, ranging in size from 1/64" to ⅛", are an important part of the complete line of Fiberglas Electrical Insulation Materials. They are being widely used for all types of tying purposes on electrical equipment, or where high strength tension member is required.

Universally adaptable Fiberglas Cords provide all of the advantages inherent in Fiberglas, such as: heat, moisture, acid resistance, and exceptionally high tensile strength-to-size ratio. For example, the minimum breaking strength of 1/32" Fiberglas Cord, number EC5-1, is 66 lbs., that of ⅛" cord, number EC5-8-T, is 274 lbs.

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Fiberglas Tying Cords are widely used for banding field coils; for wrapping string bands on small armatures; for protecting front of the commutator V-ring from flashovers on motors; as banding, on the V-ring extensions on some d-c equipment; as filling, in winding certain coils; for reset strings; and for tying slot insulation in place. It is also used to lash ends of coils in large motors and generators, and to hold spacer blocks in place.

In general, Fiberglas Cords are from three to five times as strong as ordinary electrical twines. Therefore, Fiberglas Cords, smaller in size than cords of other materials, can be used for many applications.

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Treated cord is used primarily for its increased knot strength and abrasion resistance. For general applications in the construction or repair of electrical equipment, the treated cord is preferred. Where space is to be filled, regardless of strength requirements, the untreated cord is frequently used.

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The new Fiberglas catalog EL44-7 gives performance and application data of interest to anyone concerned with electrical insulation—also facts about Fiberglas Tapes, Fiberglas-Insulated Wire and Cable, Fiberglas-Mica combinations and other Fiberglas-base Materials. Write for a copy today, and ask for the name of the supplier located nearest to you.

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OILOSTATIC TRANSMISSION SYSTEM

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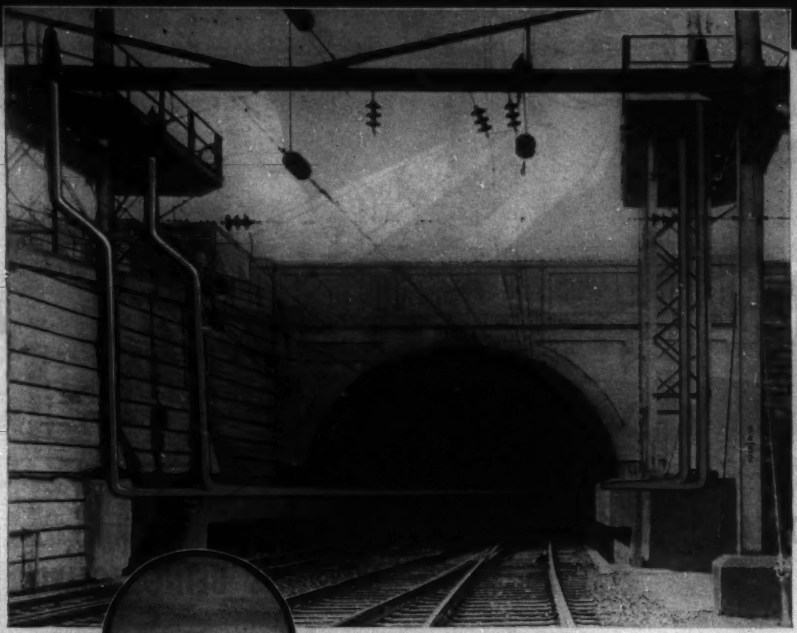

• The installation diagrammed above consists of 2 single-phase (132 kv) circuits — each 3¼ miles long. Each circuit consists of 2 single conductor 500,000 CM cables in a 7" steel pipe filled with oil maintained under 200 lbs. static pressure. Maximum cable lengths pulled were approximately 4,000 ft.

In February 1935, the Pennsylvania Railroad placed in operation the Oilostatic Electric Transmission System in its Baltimore tunnels to supply high voltage electric power for New York-Washington electrification. This system has functioned without service interruption.

In the Oilostatic Electric Transmission System, paper insulated cables are completely immersed in oil. Ruggedly constructed cables, in an oil-filled pipe line maintained under 200 lbs. static pressure, provide a simple, economical method of handling heavy loads at high voltages.

Oilostatic cable systems are suitable for electrical transmission in congested areas, for urgently needed tie-lines, for railroad electrification, for eliminating overhead construction near airports, and in tunnels and on bridges, for crossing swamps, rivers and other bodies of water.

For free literature which illustrates, diagrams, and describes the Oilostatic Electric Transmission System — or if you wish to talk over a possible installation — get in touch with our nearest district office or write to The Okonite Company, Passaic, New Jersey.

OKONITE-CALLENDER paper insulated power cables

4062

BOREAS IS THE FLYER'S BITTER ENEMY . . . BUT HE'S BEING FOILED

As engineers, we must admit that all present means of dispersing ice formations on aerofoil surfaces are only partially satisfactory—but encouraging. Most efforts have been directed to the wings.

To disperse ice on propellers, the National Research Council of Canada over a period of six years, evolved an electrical system which achieved outstanding results. It employs heater elements cemented on the leading edge of the blades and obtains power from an auxiliary alternator mounted between propeller and engine.

As a Company serving industry and laboratories with *specialized* machines, we were privileged to manufacture several generator units for these experimental purposes of the National Research Council.

NOTE.—The "stator" rotates with the propeller blades; output winding branches to the heater elements on blades; "rotor" is stationary with engine and energised by main aircraft power supply.

SMALL Electric Motors
(CANADA) LIMITED
LEASIDE • TORONTO • CANADA

LONG SCALE, WIDE RANGE VOLT-OHM-MILLIAMMETER

DOUBLE SENSITIVITY D. C. VOLT RANGES
0-1.25-5-25-125-500-2500 Volts, at 20,000 ohms per volt for greater accuracy on Television and other high resistance D.C. circuits.
0-2.5-10-50-250-1000-5000 Volts, at 10,000 ohms per volt.

A. C. VOLT RANGES
0-2.5-10-50-250-1000-5000 Volts, at 10,000 ohms per volt.

OHM-MEGOHMS
0-400 ohms (60 ohms center scale)
0-50,000 ohms (300 ohms center scale)
0-10 megohms (60,000 ohms center scale)

DIRECT READING OUTPUT LEVEL DECIBEL RANGES
−30 to +3, +15, +29, +43, +55, +69 DB

TEMPERATURE COMPENSATED CIRCUIT FOR ALL CURRENT RANGES D.C. MICROAMPERES
0-50 Microamperes, at 250 M.V.

D. C. MILLIAMPERES
0-1-10-100-1000 Milliamperes, at 250 M.V.

D. C. AMPERES
0-10 Amperes, at 250 M.V.

OUTPUT READINGS
Condenser in series with A.C. Volts for output readings.

ATTRACTIVE COMPACT CASE
Size: 2½" x 5½" x 6". A readily portable, completely insulated, black, molded case, with strap handle. A suitable black, leather carrying case (No. 629) also available, with strap handle.

LONG 5" SCALE ARC
For greater reading accuracy on the Triplett RED ● DOT Lifetime Guaranteed meter.

SIMPLIFIED SWITCHING CIRCUIT
Greater ease in changing ranges.

Write for descriptive folder giving full technical details

Precision first ...to last

Triplett

ELECTRICAL INSTRUMENT CO. BLUFFTON, OHIO

A TRACE OF Li*

and Burndy adds 20% to the strength of cast electrical CONNECTORS

Continuing its leadership in connector development, Burndy now supplies cast electrical connectors made from Burndy alloy #113L . . . a new high-copper alloy containing *Lithium. This important addition of Lithium, in correct amount, provides denser, finer grained castings . . . with tensile strength increased 20%, elongation increased about 20%, and coefficient of friction materially reduced.

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For complete information on these or any other type of electrical connectors, write connector headquarters . . . Burndy Engineering Co., Inc., 107-E Bruckner Boulevard, New York 54, N. Y.

Headquarters for CONNECTORS

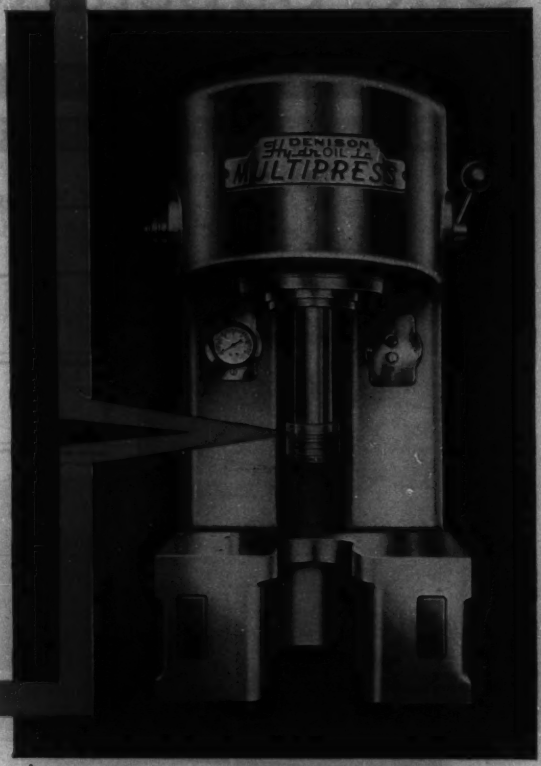
Burndy

In Canada: Canadian Line Materials, Limited, Toronto 13

Where can YOU use this amazing new VIBRATORY ram action?

(Oil-Hydraulic)

Ram action that permits short, rapidly-repeated uniform pressure strokes of regulative length, frequency, pressure and number per ram cycle



● So many startling advantages have been found in this new *exactly-controlled vibratory ram action* that, thus far, even we know only a few of its potential applications. Performance tests indicate that it may *revolutionize* scores of operations!

If your production includes *any* operation which you think might be improved by rapidly-repeated, uniform-pressure strokes, Denison engineers will be glad to adapt Vibratory HydrOILic Pressure to your specific needs! Write for information today!

* * *

This new vibratory hydraulic pressure principle is available in the equally amazing Denison Multipress—a four-ton and six-ton bench-size oil-hydraulic machine tool that performs almost any type of production operation calling for controlled pressure. *Let us send you the latest, fully-illustrated bulletin on* MULTIPRESS.

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DENISON
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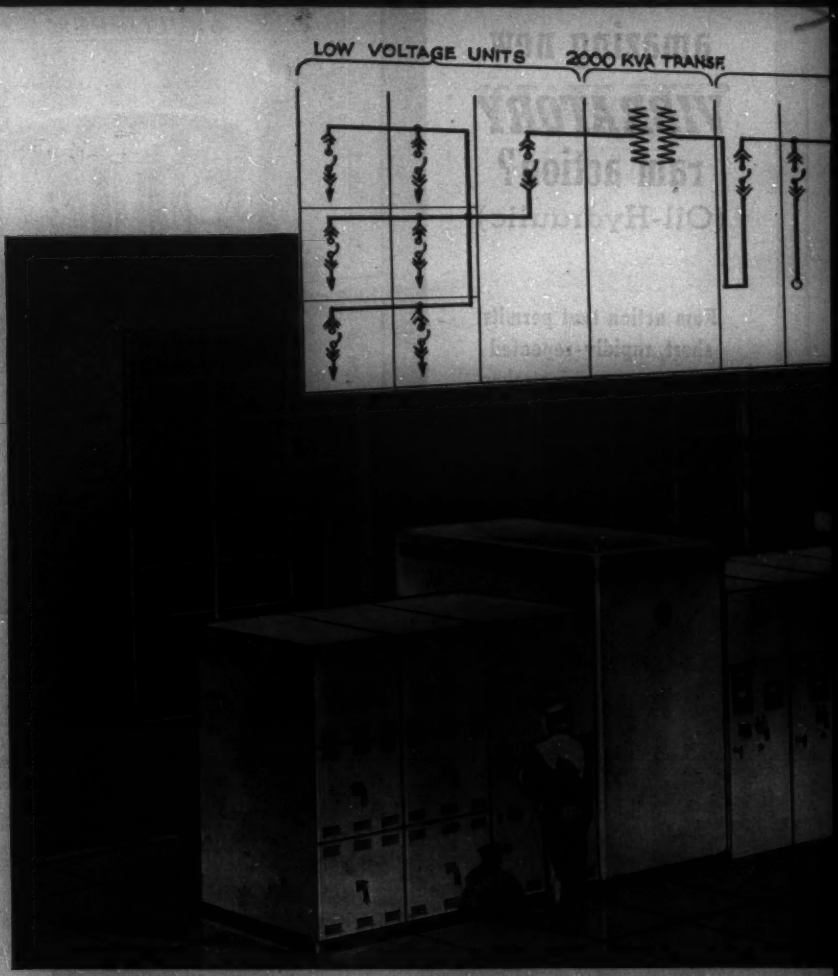
HydrOILics

HydrOILics INDICATE RIGHT KIND

One Substation Serves

ALLIS-CHALMERS NOW OFFERS A "PACKAGED" SUBSTATION

EXCITRON RECTIFIER. THE COMPACT METALCLAD UNIT

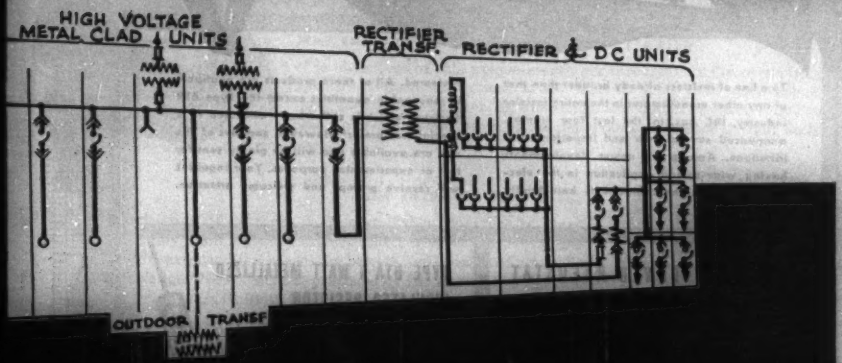


ALLIS-CHALMERS

Both A-C and D-C Loads

FEATURING AT THE D-C END A LOW MAINTENANCE SEALED

IS IDEAL FOR HIGHLY CONCENTRATED INDUSTRIAL LOADS.



IF LOADS are both concentrated and diversified—as in steel mills, foundries, and synthetic rubber plants—an Allis-Chalmers packaged substation may be "right answer" to your power distribution problem.

This compact metalclad unit, comprising a 2400 volt multi-circuit substation, and a-c and d-c load center substations, saves space, installation time, and maintenance time!

Use of the new 2000 kva dry type transformer and 150,000 kva, 5 kv "Ruptair" magnetic air circuit breakers makes the installation totally oilless. The 500 kw permanently sealed "Excitron" rectifier at the d-c end of the unit requires minimum maintenance.

Ask for more details on this modern substation from our nearby district office, or write ALLIS-CHALMERS, MILWAUKEE 1, WISCONSIN. A 1866

MILWAUKEE, WIS.

YOUR CHECK LIST OF NEW IRC PRODUCTS

To a line of resistors already broader than that of any other manufacturer in the entire resistor industry, IRC has, in the last few months, announced several new and important contributions. Among the newer developments having wide-spread application in the electronics field are the components here briefly reviewed. All of these products are available in reasonable quantities except the Type BTR Resistor, which is still wholly allocated to a special war project. However, samples of this unit are available and will be gladly sent for test or experimental purposes. Your inquiries will receive prompt and welcome attention.

TYPE PRT POWER RHEOSTAT

Rugged yet light in weight and of neat appearance the PRT conforms fully with AN3155 specs. Has heavy screw type terminals at rear of enclosed all-metal housing. Available in 25 and 50 watt models.

TYPE BTA 1 WATT METALLIZED INSULATED RESISTOR

Pencil-thin, less than ¾" in length and conservatively rated at one watt the BTA is a quality resistor throughout and meets RC30 specs. Low in operating temperature it has proportionately high wattage dissipation.

TYPE BTR ½ WATT METALLIZED INSULATED RESISTOR

Scarcely bigger than a bump on a wire (L. 1/32"-Dia. 3/32") the BTR ½-watt resistor has all the quality characteristics and features that have long made IRC's BT line "Preferred for Performance." Suitable for Army-Navy RC 10 applications. Available postwar.

TYPE FRW FLAT WIRE WOUND RESISTOR

Efficient as a tubular wire wound, the type FRW has many features that recommend it for limited space use. In 5 standard sizes to comply with JAN-R-26, specs for RW 20, RW 21, RW 22, RW 24 requirements.

TYPE GRW GRADE 1-CLASS 1 RESISTOR

Thoroughly dependable and of sound construction these completely sealed units meet or surpass every requirement of JAN-R-26 specs. Made in 7 standard sizes with power ratings of 15 to 140 watts and resistance ranges of 0.1 to 63,000 ohms.

FINGERTIP CONTROL

No bigger round than a nickel and wafer-thin, this control will find many useful applications in the smaller electronic devices. All-inclusive design eliminates the usual knob, shaft and bushing without impairing functional operation.

For more complete technical information on any of the above IRC products write to Dept. 5-N

INTERNATIONAL RESISTANCE CO.

401 N. BROAD STREET - PHILADELPHIA 8, PA.

PRECISION FOR PERFORMANCE · IRC · FIXED & VARIABLE RESISTORS ·

IRC makes more types of resistance units, in more shapes, for more applications, than any other manufacturer in the world.

a nation-wide search for scientists of tomorrow

A MAJOR NEED of America today is the discovery and development of scientific ability among boys and girls now in high school. Real ability for creative research and engineering is rare. Many who do not now have the opportunity to develop their scientific talents will be discovered and made available for America's future progress through the Science Talent Search, conducted by Science Clubs of America and sponsored by the Westinghouse Educational Foundation.

WHY THE SCIENCE TALENT SEARCH WAS STARTED

The objectives of this unique search are threefold: to discover high school seniors of exceptional scientific aptitude – to focus their attention on the need for developing scientific knowledge and skill in research – and to make the American public aware of the importance of science in their daily lives.

HOW ENTRANTS ARE TESTED

Examination of entrants in Science Talent Searches is based largely upon rigorous science aptitude tests – to determine their research ability, reasoning powers and breadth of scientific knowledge. These tests are prepared by Dr. Harold E. Edgerton and Dr. Steuart H. Britt, prominent educators and psychologists.

HOW THE SEARCH IS CONDUCTED

Each year, high school seniors all over America compete for Westinghouse Science Scholarships, of a total value of $11,000, by taking these aptitude tests and submitting original science essays. Selection of the 40 finalists in the Annual Science Talent Search is based upon their records in aptitude tests, scholastic standing, recommendation of teachers, and science essays, in the order given.

WHAT IT HAS ACCOMPLISHED

To date, 160 brilliant youngsters—winners of Science Talent Searches – have been awarded $41,500 in Westinghouse Science Scholarships. In addition, 429 winners of Honorable Mentions in the *first two* Science Talent Searches have received scholarships, valued at $132,450, from other sources. Of perhaps greater importance, a continuing study of one of the early Searches has disclosed that more *than 75% of those who entered this competition have actually gone to college – against a national average of only 35% for high school students!*

SEND FOR SCIENCE TALENT SEARCH LEAFLET

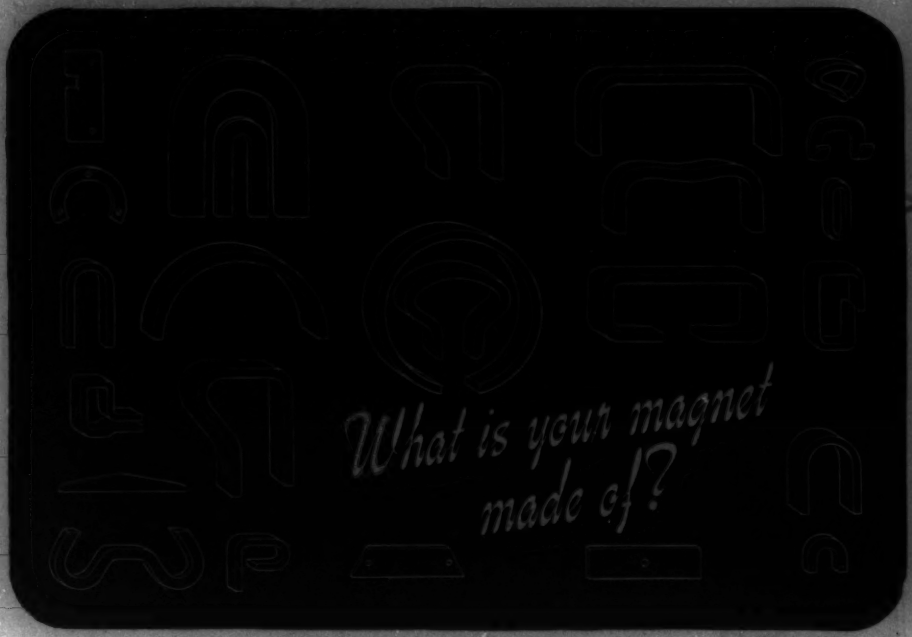
If you are the parent of a scientifically-gifted boy or girl who will be a high school senior this fall . . . or if you know of such talented youngsters . . . send for Science Talent Search Leaflet EE-85 which gives full information about these competitive awards. Write: Westinghouse Electric Corporation, Box 1017, Pittsburgh 30, Pa.

Westinghouse

PLANTS IN 25 CITIES OFFICES EVERYWHERE

Tune in: JOHN CHARLES THOMAS—Sunday, 2:30 pm, EWT, NBC • TED MALONE—Monday through Friday, 11:45 am, EWT, Blue Network

PERMANENT MAGNETS MAY DO IT BETTER



(This is the first of three advertisements regarding permanent magnet materials)

PERMANENT MAGNET STEELS

Natural successors to primitive soft iron magnets were those of carbon steel to which, later, were added chromium, tungsten or cobalt. They may be formed from rolled stock, or cast in desired shapes, and can be drilled and machined after an annealing operation. They are heated to precise temperatures and then quenched in oil or water to develop permanent magnet properties.

Materials in this group have high residual inductions and coercive forces ranging from 60 oersteds in the chromium steels to 250 oersteds in the high cobalt grades. Because these materials are machinable, they may be used to advantage in some applications requiring machining and having magnetic requirements within their limitations. Proper allowance must be made for the demagnetizing effect of stray magnetic fields and vibration, and care must be taken that their temperature limits are not exceeded.

The Indiana Steel Products Company uses numerous magnet steels and Alnico alloys in both cast and formed magnets, and has the specialized experience to select the material best suited to each specific job, engineering personnel to create the optimum design, and equipment to furnish the permanent magnets most suitable for any application. The complex factors of magnet design make engineering consultation advisable; many problems call for development or research. Write for complete information. Send for free copy of technical hand book: "*Permanent Magnet Manual.*"

★★★ **THE INDIANA STEEL PRODUCTS COMPANY** ★★★

6 NORTH MICHIGAN AVENUE, CHICAGO 2, ILLINOIS

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SPECIALISTS IN PERMANENT MAGNETS SINCE 1910

A TELECHRON SELECTOR FOR POST-WAR RADIOS

THIS carefully engineered timer gives radio receivers dramatic two-way sales appeal. It's a dependable electric clock that provides the accurate time listeners need. *But it's much more.* It turns on the set automatically at any preselected time in the morning to waken a member of the family—or the whole household—with music. It switches the set on for favorite programs during the day and evening and shuts it off at bedtime.

Set buyers will like the easy finger-tip control of this built-in Selector. There are no knobs to turn, no complicated settings, no difficult calculations. All that's needed to set the timer for any 15-minute period is to flip one of the 48 keys around the large, legible Telechron clock dial. Fifteen minutes after the set has been turned on, it will switch off unless the next key is also pulled. Keys are automatically reset to "off" position after timing periods are passed. Programs can be selected as far ahead as 10 hours.

The cost to radio set builders will be surprisingly low—less than $4. That recommends the Selector for moderate-price receivers.

The Telechron Selector is only one of the full line of automatic timing and control devices we can supply for post-war appliances. All use famous Telechron movements and self-starting synchronous motors.

For full information about this and other Telechron timers, wire or write Automatic Control Division, Dept. F.

WARREN TELECHRON CO. • ASHLAND, MASSACHUSETTS

Telechron

Instruments FOR ALL PROBLEMS OF RECONVERSION

Utilities, manufacturers and maintenance contractors will find, within the broad WESTON line, instruments specifically suited to *all* problems of electrical reconversion . . . whether they involve quick repairs, rewiring for heavier loads, relocation of equipment, new testing stands or laboratory installations, improved lighting, as well as for all electrical and electronic maintenance needs. Literature, or engineering cooperation on any instrument problem, is freely offered. Weston Electrical Instrument Corporation, 578 Frelinghuysen Avenue, Newark 5, N. J.

(MODEL 785) INDUSTRIAL CIRCUIT TESTER . . . the most versatile portable tester for laboratories, and plant maintenance, where an ultra-sensitive instrument is required. Provides 17 AC and DC voltage, AC and DC current, and resistance ranges. (dc sensitivity 20,000 ohms per volt.)

(MODEL 796) INSULATION TESTER . . . a direct-reading self-contained resistance tester that eliminates hand cranking. Tests up to 200 megohms at test potential of 350 to 500 volts dc., current at terminals only a few microamperes. Ranges 0-20-200 megohms, full scale . . . 0-5-5 center scale.

(MODEL 697) VOLT-OHM-MILLIAMMETER . . . combines a selection of AC and DC voltage, direct current, and resistance ranges in a pocket-size meter. Ideal for maintenance testing and inspection needs.

(MODEL 633) AC CLAMP AMMETER . . . for quick, easy current measurements on insulated or non-insulated conductors. The clamping jaws are simply clamped around the conductor, and readings taken. Circuits are never disturbed. A real time saver in electrical maintenance.

PANEL AND SWITCHBOARD INSTRUMENTS . . . available for all AC and DC requirements, in all types, sizes and ranges. The complete line is fully described in the WESTON Panel Instrument bulletin. Send for your copy.

(MODEL 430) AC AND DC TEST INSTRUMENTS . . . combine dependability, ruggedness, compactness and scale readability. Equipped with hand calibrated, mirror scales. Available for AC and DC requirements, and as DC and single-phase AC Wattmeters.

(MODEL 703) SIGHT METER . . . direct-reading, pocket size meter calibrated to measure light values in foot-candles, or by seeing tasks. Equipped with the WESTON VISCOR® filter, it measures all light values direct, without correction factors.

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In Canada, Northern Electric Co., Ltd., Powerlite Devices, Ltd.

ELECTRICAL ENGINEERING

Registered United States Patent Office

AUGUST
1945

The Cover: This 16-bladed 24-foot fan in the wind tunnel of the Allen Memorial Aeronautical Laboratories which generates wind velocities approaching the speed of sound has a top speed of 490 revolutions per minute and is powered by an 18,000-horsepower motor. Projecting from its hub is a conical-shaped fairing which prevents turbulence of air. Boeing Aircraft Company photo

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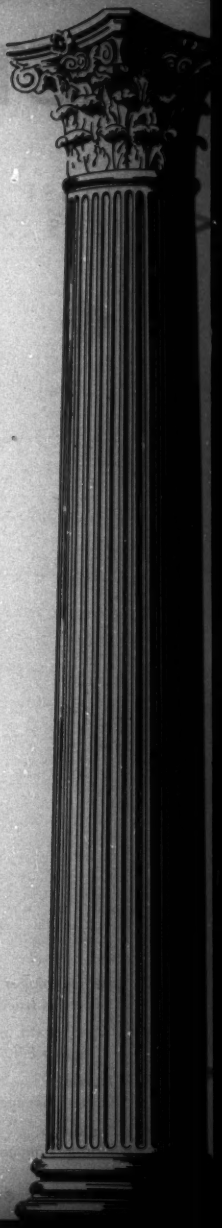

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Ship's Service Power Systems for Naval Vessels

H. G. RICKOVER
MEMBER AIEE

Equipment of ship's service electric power and distribution systems for naval vessels, the contrasting conditions of electric power systems on shore and on board ship, and the progress of these systems over the past several years are described in detail in this article.

SINCE 1883 when a 13.2-kw d-c lighting generator was installed on the crusier *Trenton*, the use of electricity on naval vessels has increased so much that today modern battleships have as much generating capacity installed for ship's service power and lighting as would be required to serve a city of approximately 125,000 people. Almost every function involved in the operation of the vessel for whatever mission it may have been designed relies in large part on electric power. In fact, failure of this power may mean the disability or even the complete loss of the vessel.

The two general types of electric systems installed on naval vessels are the electric propulsion, and ship's service electric systems. As the purpose of this paper is to describe some of the aspects involved in the design of ship's service power and distribution systems on modern naval vessels, no discussion of electric propulsion systems will be given. Suffice it to say that an electric propulsion system consists of equipment necessary for the generation, distribution, control, and utilization of electric power and forms a flexible transmission medium between the prime movers and the propellers.

Nearly all shore electric-power systems consist of a network of power stations linked together. This may include several stations in the same locality or may extend to a large number of steam and hydraulic plants covering several states. Thus, the temporary loss of the local plant normally will not cause interruption of power as demands may be supplied by other plants connected in the system. The condition on board ship is quite different. A ship is entirely dependent upon its own plant and in case of operating difficulties cannot look to outside activities temporarily to supply power or to assist in returning the plant to operation. Furthermore, electric generating plants and distribution systems on naval vessels must be capable of operating under conditions of heavy shock, heavy roll and pitch, and under extreme atmospheric conditions. It is therefore mandatory that naval vessels be provided with the most reliable and rugged equipment.

Based on an address presented at the AIEE winter technical meeting, New York, N. Y., January 24-28, 1944.

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DESIGN OF A NEW NAVAL VESSEL

Whenever a new type of naval vessel is to be constructed, the Navy General Board specifies the characteristics, purpose, and special features of the vessel. After approval by the Secretary of the Navy, a directive is issued to the Bureau of Ships to have the vessel constructed. Based on the information received from the General Board and the Secretary, the Bureau of Ships determines the design of the hull, details of the machinery including type of propulsion to be furnished, and the type of electric plant to be installed. Specifications, and contract plans showing general contours of the hull, compartmentation, and arrangement of the machinery are prepared by the Bureau of Ships. These contract plans and specifications are used in the preparation of the builders' plans.

D-C SYSTEMS

Surface naval vessels designed prior to 1933, smaller vessels of present design, and many vessels converted for naval use are equipped with d-c ship's service electric systems. Some of these are 240/120-volt three-wire systems with lighting supplied at 120 volts and power loads at 240 volts. Some have 120-volt systems for both power and lighting. Where alternating current is required for special application on vessels having d-c systems, it is supplied by motor generator sets or by independent a-c generators installed for the particular requirement. All submarines have d-c ship's service systems with power taken from the main storage batteries when submerged and from the batteries or a Diesel-driven auxiliary generator when on the surface. The voltage of the ship's service system is different in the several classes of submarines, depending on the number of cells in the main storage batteries. Submarine lighting circuits are either direct current supplied from the storage batteries or through motor generator sets, or alternating current supplied through motor generator sets.

A-C SYSTEMS

Battleships, aircraft carriers, cruisers, destroyers, destroyer escorts, and the large auxiliary vessels designed since 1933 are provided with 450-volt three-phase 60-cycle a-c systems. Lighting circuits at 117 volts are supplied by step-down transformers taking power from the 450-volt line. A few of the earlier installations and some vessels converted to naval use have a-c systems of different voltage or frequency. Where direct current is required for special applications, such as searchlights or "degaussing," it is usually provided by motor generators. On destroyers and smaller vessels direct current is supplied by oversize exciters direct-connected to the a-c ship's service generator sets.

SHIP'S SERVICE GENERATORS

The size of the electric plant is determined after the type and size of the vessel have been specified, and all the propulsion- and auxiliary-machinery requirements are known. The capacity of the electric plant is based on a power analysis of the vessel operating under conditions requiring the maximum amount of electric power. On combat vessels this condition would exist when the vessel is in battle, whereas on naval auxiliary vessels, such as a destroyer tender, the maximum load would occur when the vessel is utilizing most of its shop

equipment. Likewise, for cargo-carrying vessels, such as a tanker, the maximum demand for electric power would occur when the vessel is using the large oil-handling pumps. Thus every operating condition for each type of vessel must be carefully studied to estimate the maximum demand for electric power.

In most cases, the total plant has capacity to carry twice the calculated maximum electric-power load. The excess capacity is provided for two major purposes:

1. For sufficient power to operate under conditions where 50 per cent of the electric plant has been lost.

2. To allow for increased electric loads, such as additional guns, new or larger auxiliaries, and new communication equipment.

After the required amount of electric power has been determined, standard-size generators of a rating to obtain as many units as practicable without jeopardizing operating efficiency are selected. These are known as ship's service generators, and are usually controlled from either two or four generator and distribution switchboards, depending on the number of generators installed and the type of the vessel. In addition to the ship's service generators, one or two Diesel-powered emergency generators are installed in locations widely separated from the main electric-power plant, for use when the ship's service generators are inoperative. The locations of the generators and switchboards are selected to obtain as much separation as practicable so that damage to any one section of the vessel will not disable the entire electric plant. On large vessels, the switchboards are separated from one another by at least one watertight compartment.

CHARACTERISTICS OF GENERATORS AND VOLTAGE REGULATORS

Turbine or Diesel-driven generators or both are installed in naval vessels. On ships having steam or steam-electric propulsion, turbogenerators supply the ship's service power, while Diesel generators are used for emergency service. Diesel-propelled ships use Diesel generators for ship's service power.

A-c turbogenerator sets range in size from 200 to 1,500 kw and consist of a turbine of the solid-rotor design running at speeds of from 8,000 to 10,000 rpm having either a single or double helical gear with a 60-cycle 1,200-rpm generator and a direct-connected exciter. D-c turbogenerator sets range in size from 60 to 750 kw and consist of a turbine of the built-up rotor design running at speeds of approximately 6,000 rpm with a single helical reduction gear connecting a 1,200-rpm generator.

Diesel-generator sets consist of a Diesel engine of either the two- or four-cycle type and a direct-connected generator of 10 to 500 kw direct current or 30 to 850 kw, 60 cycles, alternating current, running at speeds from 600 to approximately 1,200 rpm. Diesel-driven a-c generators employ direct-connected exciters.

Due to special conditions incident to naval operation, generators must incorporate many mechanical features not required for shore installations. They must be as small and light as design will permit and constructed for maximum reliability and ease of maintenance. They must be constructed of steel throughout to withstand shock and must have maximum rigidity to insure operation during roll and pitch of the vessel. They must have clearances, creepage distances, and insulation adequate to withstand ambient temperatures of 50 degrees centigrade and adverse conditions of humidity, salt air, and oil vapors incident to the machinery spaces.

Many special design features, particularly for a-c machines, are likewise required. Practically all a-c generators are of the salient-pole design. Operating conditions require that the transient reactance not exceed 17 to 27 per cent and that the subtransient reactance meet requirements of 10 to 13.2 per cent (depending upon the size of the machine). The short-circuit ratio is greater than 1.0, the negative-sequence reactance is kept small (average value of 15 per cent), and the response of the voltage-regulating system is much higher than required by commercial designs.

These design limitations have been determined from extensive developments and tests conducted by both the Bureau of Ships and the electrical manufacturers and are in keeping with the following considerations:

(*a*). The relatively small size of the electric plant compared with the total connected load.

(*b*). The desire to eliminate superfluous equipment such as reduced-voltage-type motor starters.

(*c*). The large single-phase loads which are present in certain types of vessels resulting in phase current and voltage unbalance.

(*d*). The need to control instantaneous and sustained values of generator short-circuit current in order to co-ordinate circuit-breaker selective tripping and to limit the short-circuit current to values within interrupting capacity of the circuit breakers.

(*e*). The desire for maximum stability in the generator system.

(*f*). The need to reduce to a minimum the voltage disturbance (dip and length of time to recover to approximately normal) resulting from the sudden application (motor starting) of low-power-factor loads in the range of 50 to 100 per cent of the current rating of the generator supply.

Integral parts of the generating system are the exciter and the voltage regulator. Due to their superior performance and low maintenance, all voltage-regulating systems being provided for new naval vessels employ either the direct-acting rheostatic type, functioning in the field of a standard shunt or stabilized shunt exciter, or a rotary-amplifier type. The latter is a recently developed regulator consisting of a specially designed exciter whose output to the field of the a-c generator is a predetermined function of a system voltage change as interpreted by a static control device. Within the limits set by the generator reactances and time constants, the regulating system is responsible for maintaining regulated voltage under gradual changes of load and also for minimizing the time and amount of voltage dips or rises on sudden application or removal of large loads. These features as well as many other regulator operational points are rigidly specified and the generators tested for compliance.

Additional limitations are placed upon the generator designer because circuit breakers employing shunt trip coils are operated from the varying exciter voltages. Since these coils can operate only over a given range of voltage, the designer is limited to a maximum–minimum voltage range for excitation purposes. Although these special requirements tend to increase the size of generators, units constructed for naval use and meeting specification requirements are lower in weight and smaller in size than commercial generators of comparable ratings.

D-c generators of the straight shunt type are used for all except a few special applications. Shunt generators are preferred because of their stable parallel operation without the use of equalizer connections.

SHIP'S SERVICE DISTRIBUTION SYSTEMS

The design of the ship's service power distribution system is governed by the following requirements which are essential for naval vessels:

(*a*). Maximum reliability and continuity of service.

(*b*). Simplicity of operation and ease of maintenance.

(*c*). Flexibility to meet growing or changing-load conditions with minimum disturbance to the original system.

(*d*). Minimum weight and space.

The elements of a typical ship's service power-distribution system are shown in Figure 1. It is a radial system with provisions for interconnecting the main power sources by means of bus-tie circuits between the main switchboards so as to form a closed loop. In addition to the ship's service generating plant and distribution system, an emergency ship's service power system is also provided. This consists of one or more Diesel-engine-driven generators, associated switchboards, and distribution system. The emergency distribution system is energized by normal and alternate feeders from the main power system through bus-transfer switches. Upon failure of both of these supplies, the

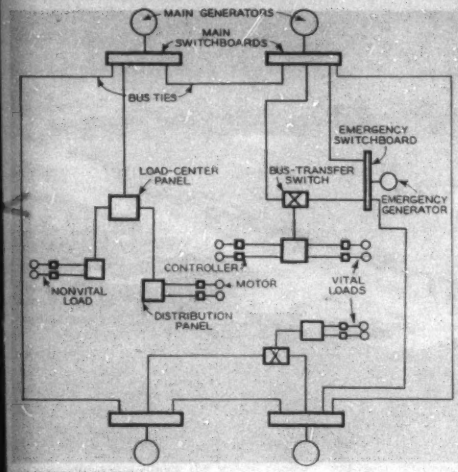


Figure 1. Typical ship's service power distribution system

emergency Diesel generator is automatically started and connected to the emergency bus.

A-c systems are used in the majority of installations, particularly those of large capacity. Power is generated and distributed at 450 volts, three phase, 60 cycles, and the system is delta-connected and ungrounded. Electric auxiliaries are built for 440 volts. Lighting and miscellaneous small-power loads are supplied at 117 volts through step-down transformers. D-c systems are used on some vessels where the majority of the auxiliaries require wide speed control such as on salvage vessels or vessels having a large number of cranes or hoists. D-c systems are ungrounded and are either 120 volts, two wire, or 120/240 volts, three wire, depending on the size of the total load and the ratio of power to lighting loads.

For a-c systems each individual load, that is, motor or transformer, is supplied by a separate feeder from a distribution panel. Insofar as practicable all loads associated with a common function, or closely related to that function, are supplied from the same distribution panel. The distribution panels are in turn supplied from the main switchboard either directly or through load centers. Load-center panels are located in the approximate center of the load area. Some vital loads, such as the steering gear and main turrets, are always supplied directly from the main switchboard.

In arranging the loads on distribution panels and load centers all nonvital loads, such as galleys and shops, are segregated from vital loads such as guns, steering gear, and engine-room auxiliaries. Feeder circuits to nonvital loads are called general circuits, and those to vital loads are called battle circuits. The latter are run within armor protection where it is practicable.

All vital electric loads are provided with at least two sources of supply. This is accomplished by means of a normal feeder from one main switchboard and either an alternate feeder from another main switchboard or an emergency feeder from one of the emergency switchboards. It would be desirable to obtain standby power for all vital loads from the emergency system. However, the emergency generating plant is of small capacity with respect to the main plant and to the size of the total vital load. For this reason certain large vital loads, such as main turrets, catapults, and airplane elevators, invariably receive standby power by means of an alternate feeder from another main switchboard. The steering gear is often supplied with an emergency feeder in addition to normal and alternate feeders.

Transfer of the vital loads from the normal to the standby power source is accomplished by bus-transfer switches. Manual bus-transfer switches are preferred because of their greater reliability and simplicity of operation. However, automatic bus-transfer switches are used under the following conditions:

(*a*). Where the location of the bus-transfer switch must be remote from or not readily accessible to the electric auxiliary which it supplies.

(*b*). For the steering gear on vessels provided with one rudder.

(*c*). On vital loads where rapid restoration of power supply is essential.

A time delay is provided in the transfer operation of all bus-transfer switches to avoid excessive current transients during switching.

In providing standby-power sources to vital loads, the selection of the power source (generators and switchboards) and the arrangement of the cable runs for the normal, alternate, or emergency feeders are such as to obtain the maximum separation afforded by the compartmentation of the vessel, and the cables are protected by armor to the greatest practicable extent.

Voltage drop seldom determines the cable sizes in ship's service distribution systems because of the low per-unit impedance of the cables and the short length of the circuits involved. However, it is necessary that the voltage drops be checked and the system regulation maintained within definite limits. On d-c systems the permissible cable-voltage drop is 8 per cent while on a-c systems the drop is limited to 6 per cent under normal operation and to 12 per cent under motor-starting conditions. On a-c systems it is particularly important to check the cable-voltage drop under motor-starting conditions to ensure adequate motor-starting torque and to avoid applying excessively low voltage momentarily to motors already running.

With current-carrying capacity the dominant factor in the choice of cable sizes, the connected loads must be carefully analyzed to determine the maximum demand load on each feeder circuit if a distribution system of minimum weight yet adequate capacity is to be obtained. The calculation of feeder loads involves consideration of the following:

(*a*). The function of each auxiliary connected to the feeder to ascertain the diversity of loading.

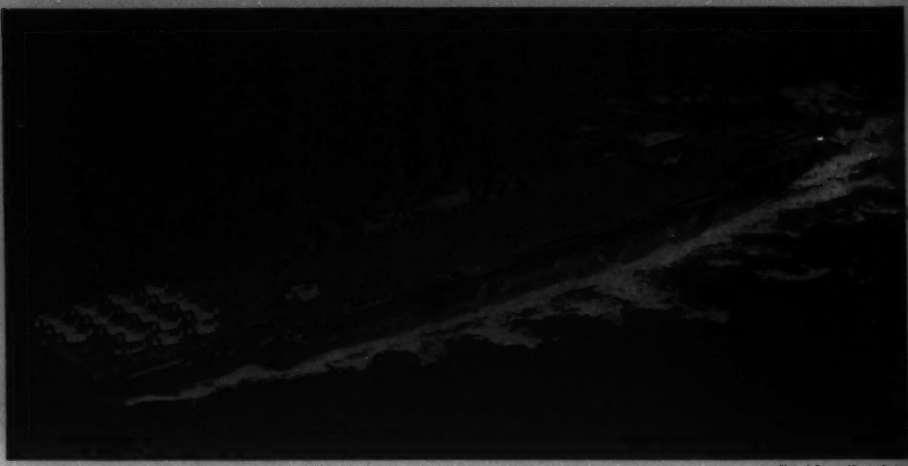
(*b*). The character of each load, that is, whether intermittent or continuous.

(*c*). The allowance of suitable spare capacity for load growth.

In evaluating each of the above factors and to arrive at a maximum load on the feeder circuit, the several possible operating conditions of the vessel (anchor, cruising, battle) are studied. In addition, the influence of the short-time rating of the cable is considered, particularly where the load is of a widely fluctuating nature.

The current-carrying capacity of cables is influenced by the ambient temperature, grouping of the cables, and thermal characteristics of the surrounding materials. In naval service, the large number of cables, limited space, restricted ventilation, and localized high ambient temperatures combine to produce installation conditions particularly unfavorable from the standpoint of cable current-carrying capacity.

The increase in the use of electrically driven auxiliaries on naval vessels has produced large increases in the installed generating capacity. This fact, together with the necessity for maintaining a high degree of reliability and continuity of service, has emphasized the importance of providing adequate fault protection. Such protection is primarily concerned with the automatic isolation of a fault with mini-



United States Navy photo

Figure 2. Port-bow aerial view of an aircraft carrier

mum damage and with minimum disturbance to the remainder of the system. Automatic thermal overload protection of the system is not required since reliance is placed on personal supervision to avoid excessive loading.

The basic requirements for fault protection on ship's service power distribution systems are as follows:

(*a*). Maximum protection of electric apparatus and circuits.

(*b*). High-speed clearing of faults.

(*c*). Selective operation under fault conditions.

(*d*). Adequate interrupting capacity in all circuit-protective devices or the provision of suitable back-up protection.

(*e*). Adequate thermal capacity in all circuit-protective devices.

(*f*). Simplicity of operation and ease of maintenance.

The need for simplicity of operation and ease of maintenance plus restricted space requirements makes it necessary to avoid the use of complex types of fault-protective systems requiring a large number of relays, current transformers, and pilot wires. For this reason, circuit breakers having integral direct-acting inverse-time-delay overcurrent-trip attachments are the most satisfactory method of securing fault protection on ship's service power systems. However, on bus-tie and generator circuit breakers, inverse-time-delay overcurrent relays are used to trip the circuit breaker through a d-c shunt trip coil energized from the generator exciter.

To obtain selective operation of the protective devices over the wide range of possible fault currents using inverse-time-delay overcurrent protection exclusively, reliance is placed on providing successively increasing time delay on each protective device in series between the load and the generator. On this basis very close tolerances are required on the time–current tripping characteristics of each protective device in order to avoid excessively long time settings on the generator and bus-tie circuit breakers and consequent delay in clearing bus faults. The development of special tripping devices has been necessary in order to achieve desired operation.

In order to provide adequate and reliable fault protection the designer must know the value of current to be expected on short circuits. Calculations are made of

1. The maximum available short-circuit currents to determine the required interrupting ratings of the circuit breakers.

2. The minimum available short-circuit current to check the minimum trip point of the protective devices.

3. The decrement curve of the short-circuit current of each generator to check the overall co-ordination of the protective system.

DESIGN AND CONSTRUCTION OF SWITCHBOARDS

Many factors not normally considered for shore-installed switchboards assume major importance in the design and construction of switchboards for naval vessels. These switchboards must be capable of withstanding, without damage or maloperation, the severe mechanical shocks induced by enemy shells, torpedoes, bombs, and mines. Switchboards aboard naval vessels are subjected to severe lateral forces caused by rolling and pitching of the vessel. Temperatures in which these switchboards must operate are normally much higher than those encountered on shore. To complicate the problem more, limitations of available space and weight dictate that the switchboards be as small and light as practicable.

The necessity for operating naval vessels with newly trained personnel together with unpredictabilities of human reactions under stress of battle makes it imperative that switchboard operation be made simple. Similarly, automatic devices must be simple in construction and operation as delicate adjustments or repairs to intricate equipment may be impossible or require excessive time during critical periods.

To develop switchboards of maximum inherent reliability for these conditions extensive studies and tests have been conducted. From these investigations the present switchboards for naval shipboard installations have emerged. They are of all-steel construction, dead-front, sectionalized, and they utilize bench-type control units for mounting instruments and controls. In addition to the advantages of sectionalized construction in confining faults or fire, increased resistance to mechanical shock is obtained. For maximum strength and rigidity, box-type frameworks fabricated from steel angles and channels are used. Welded construction is used except for parts that must be removed for equipment repair or replacement. To prevent damage from water dripping or spraying into the switchboard, solid top sheets are used overhanging the front, rear, and side sheets. Solid end sheets are used but the rear enclosures are of expanded metal to permit inspection and the rapid application of carbon dioxide should a fire develop within the switchboard.

Switchboard sections are internally compartmented to segregate circuit breakers from the bus and to separate large circuit breakers from one another. Drawout-type circuit breakers are used to facilitate their rapid replacement without the necessity of contacting live parts or de-energizing the switchboard.

Bus work is rigidly supported to prevent its dislodgement under severe shock. Special attention is given to the method of supporting bus work as severe shock can cause large deflections in unsupported sections causing flashovers or even welding of adjacent busses.

Improved insulating materials have been developed which have greatly increased fire-resistant qualities and structural strength.

Special attention is given to the arrangement of instruments and control switches so as to permit rapid switchboard operation under battle conditions. All component parts (circuit breakers, relays, instruments, and voltage regulators) are designed and constructed to be capable of proper operation under the severe conditions likely to be encountered.

LIGHTING SYSTEMS

Lighting systems on naval vessels are similar to commercial installations except that weight, space, and reliability are given greater consideration. Incandescent lamps have proved to be the most reliable source of illumination. Fifty- and 100-watt lamps designed to withstand shock and vibration are used for all except special applications. Lighting is supplied from the 450-volt three-phase power system through step-down transformers to three-phase 117-volt distribution panels fitted with 60-ampere fused tumbler switches.

Lighting circuits essential to the operation of the vessel are provided with bus-transfer switches which automatically connect the lighting to a standby source of power in the event the normal source fails. The standby source for vital lighting circuits is usually the emergency Diesel generator. Portable battery-operated lanterns located along main passageways and in important work areas provide illumination in the event all other lighting fails.

In wartime, naval vessels must operate from sunset to sunrise under "darkened ship" conditions. No lights are to be visible from outside the vessel. Low-level red-light illumination is used for necessary instrument lighting on the bridge or other exposed areas. Low-level red-light illumination is also installed in crews' berth spaces and main passageways to provide for personnel movement in these areas. Red-light illumination has the further advantage of allowing personnel whose duties involve seeing objects or performing tasks in the dark to obtain and maintain dark adaptation of their eyes.

MAIN WIREWAYS

The numerous cables installed in a naval vessel are securely mounted in wireways. These consist of steel-frame hangers welded to the ship's structure. Where practicable they are located below the waterline since this location is less susceptible to damage from enemy gunfire. Where alternate feeders are provided for vital loads, each set of feeders is located in a different wireway. To prevent all feeders from being damaged by a single casualty, the wireways running in the same direction are separated by being located on opposite sides of the vessel or by being located on different decks.

Where possible, wireways are laid out to avoid passing through powder magazines or ammunition-handling rooms. This eliminates danger from overheated cables in these spaces in the event of a short circuit or overload. When it is impossible to route the cables through any other space, the cables are enclosed in a steel duct.

IDENTIFICATION TAGS

To assist in tracing or identifying any of the thousands of cables running through the average naval vessel, each cable is marked with a metal tag. The tags are attached to the cable on each side of a bulkhead or deck they pass through and are embossed with the feeder number or symbol. The tags are of different colors to indicate the different systems. To facilitate tracing of cables through the many wireways, individual damage diagrams are furnished. These show all important power systems and indicate the location of the feeders throughout their run. Normal and alternate sources of power are shown in different colors to assist in quick location under casualty conditions.

PROGRESS FROM EXPERIENCE

The design of ship's service electric power and distribution systems for naval vessels as outlined in this article is the culmination of experience gained from the operation of a large number of vessels under war conditions. With the co-operation of the electrical industry and the shipbuilding yards, new equipment was developed and system-design changes made as soon as practicable after operating experience indicated such action to be necessary. It is believed that considerable progress has been made during the past several years and that there will be fewer casualties resulting in the loss of all or a portion of ship's service electric power during battle periods. Constant studies and developments are being made to improve further the reliability of ship's service electric power and distribution systems.

X Rays Afford New Means of Chemical Analysis

Shooting a beam of X rays through an unknown chemical substance to see how much of the radiation is absorbed, is a rapid means of identifying the elements of which the material is made. This method is being used in studies conducted by Herman A. Liebhafsky and E. H. Winslow in the research laboratory of the General Electric Company, Schenectady, N. Y. Doctor Liebhafsky explained that X rays are intimately related to the inner atom and so furnish a means of counting the number and indicating the kinds of atoms by which they are being absorbed.

TESTING METHODS

X-ray absorption as an analytical method is made practicable by a photoelectric X-ray intensity meter developed by H. Millard Smith, another General Electric research laboratory scientist. The invisible X rays fall on a fluorescent material, which becomes luminous where they strike. This material, called a phosphor, is painted on the glass envelope of a phototube of the multiplier type. With such a tube the light from the phosphor falls first on a sensitized surface within the tube and electrons are emitted from it. These electrons fall on a second surface from which still more electrons, in larger quantities, are discharged. They fall on a third surface and the yield is still further increased. Then even more stages are used. The electrons are multiplied and those from the last stage result in a small electric current which can be amplified still more with other electron tubes, and measured with an appropriate meter. The photoelectric meter can measure very weak intensity X rays and also can detect very slight variations in their intensity. For example, if the X rays are passed through a pile of 100 sheets of paper, the difference in absorption caused by the addition or removal of a single sheet produces a noticeable effect.

In the analytical method developed by Doctor Liebhafsky and Doctor Winslow, which has thus far only been set up experimentally, the solid or liquid sample is placed in a glass cell $^1/_4$ inch in diameter and 6 inches long. For gases a two-foot cell is employed. The cell is in a vertical position above the X-ray tube and a narrow pencil of the rays is sent upwards through it. The rays then fall on the phosphor around the multiplier phototube, which is enclosed in a lead housing. The current from the phototube is amplified and its intensity read on a meter. Comparisons are made of the absorption of the cell with and without the sample. Filters, made of various metals, can be placed in the X-ray beam to secure radiation of different wavelengths.

Use of Drugs in Resuscitation From Electric Shock

C. K. DRINKER

FOR MANY YEARS I have encountered the apparently irresistible compulsion of doctors to give some sort of hypodermic injection to patients overcome by carbon monoxide, close to death from submersion, or in desperate straits from electric shock. At one time in a long experience I listed, as well as the records permitted, the different drugs given in carbon-monoxide emergencies by ambulance physicians in New York, N. Y. Nothing in the traditional teaching of medical students was left out.

Let us consider an instance of electric shock in which the victim is being given artificial respiration, obviously unable to breathe, and whose heart and circulation may or may not be operating. The questions which arise are whether any drug can be administered which will at once improve the chances for reviving the breathing or aiding the condition of the circulation.

STIMULANTS TO BREATHING

The following drugs can be shown by animal experimentation to stimulate breathing. All can be given intravenously or under the skin by injection.

1. Strychnine Sulphate. This alkaloid has a stimulating action on the spinal cord, the medulla containing the respiratory center, and upon the brain. But in dosage of nonpoisonous size, strychnine has no appreciable effect on breathing and, when given in sufficient amount to stimulate breathing momentarily, is eventually depressing to respiration and thus adds to, rather than remedies, the condition of the patient. The fact is that all medical men have so wholesome a respect for strychnine as a poison, that such injections as are frequently given are so small as to be both ineffectual and harmless.

2. Picrotoxin. This drug is a strong stimulant to the nervous system, particularly the lower brain and medulla—where respiration originates. However, it has been shown that when enough picrotoxin is injected to stimulate breathing convulsions result. Picrotoxin, used carefully, under hospital conditions has proved useful in combating poisoning due to the barbiturates such as veronal, but has no place in emergency failure of breathing from electric shock.

3. Metrazol. This drug is related to camphor, and has had extensive use in the treatment of certain sorts of insanity by the production of generalized convulsions. This means it is a strong stimulant of the nervous system, but it has no conspicuous effect on breathing and has no value in respiratory failure from electric shock.

Stimulants to the heart and circulation—what they do, what they fail to do—observations on the practice of young doctors in treating "shock" cases and the findings of a long experience in the study of administering drugs, are discussed in this article by a medical doctor.

4. Coramine (Nikethamide). This is a relatively new drug and has some promise as a stimulant of a depressed breathing center. This value is, however, very uncertain and nothing so far claimed for it makes the compound worth serious consideration in electric-shock therapy.

5. Caffeine Sodium Benzoate. This caffeine compound is suitable for intravenous injection and caffeine, even in enormous dosage, seems devoid of harmful effects of serious sort. There is no doubt of the general stimulating effect of caffeine upon the central nervous system, breathing center included. I think it fair to describe the action as a sort of oiling of staggering nerve machinery. It thus makes normal processes in the breathing center go on more readily, and I know of no evidence that the drug can or has done harm. An intravenous injection of caffeine sodium benzoate is not out of place in any sort of respiratory depression, but the injection must be directly into the blood by vein, not a simple hypodermic (under the skin), since prompt action is imperative.

6. Alpha Lobeline. This drug had popularity as a respiratory stimulant about ten years ago, and has dropped out of use due to its very capricious effect as a stimulant to breathing and its emphatically disadvantageous effects on the heart and circulation.

STIMULANTS TO THE HEART AND CIRCULATION

The condition of the heart and the blood circulation as a result of electric shock is far better understood now than it was even a few years ago. Divested of all the medical description possible, it seems to me the following circulatory derangements may be met.

1. The shock, by passing through the medulla, may have stopped the breathing and left the circulation of the blood somewhat impaired but not seriously so. This is the ideal case for resuscitation. But if four or five minutes of absent breathing intervene before artificial respiration is started, the heart and blood vessels will begin to show the effects of oxygen lack. Oxygen will remedy this condition and no injection or treatment other than artificial respiration is required or advisable.

2. The medulla, in addition to the breathing center, contains, in very small space, the centers for regulating the heart rate, particularly for slowing the heart and for regulating the blood pressure by controlling the calibre of the smallest blood vessels. One may thus expect that a shock which stops breathing can readily affect nearby units concerned with the circulation. This occurs and, consequently, the situations resulting may be quite varied. A few of them are as follows:

(*a*). Breathing may be absent and the heart very slow and weak with low blood pressure.

(*b*). Breathing may be present, the heart slow, and the blood pressure variable, but becoming low.

(*c*). Breathing may be irregular with a tendency to stop, the heart slow, irregular and weak, and the blood pressure low.

Obviously, these possible situations may vary between themselves so that in each case the condition of the circulation can be appraised only by a competent physician. By "competence" I mean a man capable in cardiology and with at least some knowledge of the consequences of electric shock. Very few doctors meet this last requirement and so, lacking in the necessary discernment they supply treatment which does not meet the specific requirements of the case.

Artificial respiration for absent or inadequate breathing is, of course, essential, since lack of oxygen will make the condition of the circulation rapidly grow worse. If breathing is feeble and unreliable, the oxygen–carbon dioxide in-

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halation is helpful. Absolute rest is imperative.

If the blood pressure continues to remain low and the heart feeble so that the patient begins to be in danger for circulatory inadequacy, the physician may consider giving an intravenous injection of a small dose of adrenin or ephedrine. In either case the injection should be given very slowly and should be understood to be a last resort. Caffeine sodium benzoate, discussed in the section upon breathing, should have been given early in the management of the case and will still benefit the circulation.

3. The shock by passing through the heart may cause ventricular fibrillation. The patient is dead white, not bluish. No pulse can be felt and after three or four breaths respiration ceases. Such patients are often given adrenin injections through the chest wall directly into the heart.

Evidence is increasing that ventricular fibrillation occurring spontaneously in man, though usually fatal, occasionally ceases with return of the heart to normal rhythmic beating. There is no reason to believe the same thing may not happen after electric shock, but such an event must be very rare.

There is no practical procedure which affects the fibrillating heart muscle and an intracardiac injection of adrenin can be relied upon to do but one thing; namely, make fibrillation worse, so that any chance of spontaneous shift to normal pulsation is lost.

These observations are intended in no way as a reflection on young doctors and their training. The drugs injected very definitely can be shown to stimulate breathing but not in the dosage or under the circumstances which are of consequence in the emergencies in which we are interested.

At the present time there is no substance which can be given by injection which benefits the breathing significantly. As stated in a foregoing paragraph, caffeine sodium benzoate intravenously may be useful but has no specific potency.

I believe the Edison Electric Institute might do well to consider financing research looking toward the discovery of some substance which will be of substantial aid to the respiratory center, much as does caffeine, but really efficient. I do not think any agency so completely dependent upon the attendance of a physician, as is an intravenous injection, can be of primary consequence in resuscitation from electric shock, but year by year we have instances of artificial respiration carried out for minutes to even many hours with eventual recovery. It must be clear to every one that the most our crews trained in artificial respiration accomplish during their period of effort is to substitute artificial breathing for absent natural breathing. They merely give the patient a chance to recover by arresting asphyxia. I believe more than this could be done in the direction of finding some direct aid to the respiratory center, and that in such a direction we will see our greatest advances in the resuscitation of the most serious electric accidents.

Electronic Control of Furnace Temperatures

The development of a vacuum-tube thermocouple device characterized by its anticipating nature, increases the sensitivity and response of conventional temperature controls by 1,000 per cent according to M. J. Manjoine, research engineer of the Westinghouse Electric Corporation, East Pittsburgh, Pa. This instrument consists of two thermocouples of different thermal capacity and an electric heating element, enclosed in an evacuated glass envelope:

1. To cause heating of the thermocouples by radiation.
2. To minimize room-temperature effects.
3. To prevent deterioration of the elements.

Changes in electric-furnace temperatures are anticipated and corrective steps taken to minimize the cyclic swings in temperature characteristic of most furnace controls. When the temperature of a furnace is controlled by a single thermocouple within the heating chamber, the temperature rises sharply until it reaches a predetermined point where the control operates to disconnect the furnace from the power line. Because of the large thermal capacity of the heating elements and the furnace itself, the temperature continues to rise to a maximum and then beginst of all. At a present minimum temperature which may coincide with the maximum, the controls again connect the furnace to the line. Here again the flywheel effect of the furnace thermal capacity causes the temperature to continue to drop until a minimum is reached at which point the temperature again begins to rise. The overshooting on the heating and cooling portions of the control cycle results in a considerable temperature range between the high and low temperatures of the cycle.

The anticipator, because of the different characteristics of the thermocouples used, reacts to temperature changes quicker than the furnace and initiates the control operation sooner and minimizes temperature fluctuation. The two thermocouples in the instrument and the control thermocouple in the furnace are connected in series so that the polarity of the couple with less thermal capacity is additive and the couple with greater thermal capacity is subtractive with respect to the furnace couple.

The heating element of the instrument is energized by the power source connecting the control mechanism and the relays that operate the main power contactors. Thus the furnace and instrument-heating elements operate together. The two couples in the instrument are equidistant from the heater but the element with the lesser thermal capacity is the one which reacts first to changes in heater-element temperature.

When the two couples in the anticipator are at the same temperature, the voltage from the control thermocouple to the control mechanism is constant. At the time that the control thermocouple institutes a change in control current, such as, starting the heating part of the cycle after it had been off, the change is felt first in the two thermocouples in the anticipator. However, the thermocouple with the lower thermal capacity heats faster than the other and the thermocouple voltage at the temperature control mechanism is increased. This increased voltage causes the controller to change to cooling, thus preventing the furnace temperature from overshooting the desired maximum. When the opposite action takes place and the furnace is in the cooling portion of the cycle, the anticipator thermocouple with larger thermal capacity cools more slowly and its reversed polarity causes the control mechanism to change to heating and keep the furnace temperature from overshooting the minimum limit. A variable resistance in the heater circuit of the anticipator provides a means of controlling the frequency of operation of this supervisory furnace-temperature control.

The instrument heater reflects the line voltage dip (or rise) much quicker than the furnace-heating elements and the control is properly energized to correct for the power variation before the need is recognized by the thermocouple in the furnace.

Meteorology—Aid to Electrical Engineers

F. J. MAHAFFY

A meteorologist dispels popular notions upholding either the infallibility or the invariable error of the predictions of the "weather man." A middle-of-the-road discussion examines recent advances that have broadened the range and scope of weather prediction, the factors entering into the forecasting process, and specific meteorological information the electrical industry can expect for aid in both its long-range and day-to-day operations.

SINCE the beginning of the present war the science of meteorology has been the subject of increasing interest on the part of the general public and the popular press. Many articles have been published on the use which the military authorities are making of the science. It is claimed, for example, that the Nazis had accurate long-range forecasts on which they timed their campaigns in Poland and France. More recently a great deal has been heard of how the date for the invasion of Europe was decided by the meteorologists. In addition to this publicity various claims that the weather can be forecast weeks and even months ahead with surprising accuracy have been published. It is notable that such claims as the last have been confined to the popular press. Along with this heightened interest has gone a growing use of meteorology in various industrial and commercial activities.

The question that no doubt occurs to many persons is: why should meteorology now be receiving such prominence when it is not a new science and its use has not been considered worth while heretofore?

Two or three reasons exist for this. In the first place certain industries always are looking for new ways to improve their efficiency. In second place it is quite probable that certain benefits might have been obtained before, if the applications of meteorological science had received the intensive study they now are receiving. The principal reason, however, is that important advances have been made in the last few years in this science.

The main purpose of this article is to outline the importance of these advances, to try to outline in a realistic manner just what modern meteorology can do for the electrical engineer. It will try to penetrate the smoke screens of publicity and to avoid confusing what can be done now with what it is hoped can be done at some future time. Knowing this and also knowing what problems the weather creates for him, the engineer should be able to decide where he can put meteorology to practical use in his own field. A few places where the electrical engineer is now using meteorology are indicated and a few suggestions about where further study might be profitable are offered.

The average person has obtained most of his knowledge of meteorology in high school, where it was dealt with in two or three hours of a general-science course. It is a matter for regret that very few Canadian universities deal with the subject at all. This probably explains why the general knowledge of this subject in Canada is anywhere from 20 to 30 years behind present developments.

It is not intended to attempt a full outline of these developments, but to show:

1. What the advances in the science are that have increased its usefulness.

2. Just how far our present knowledge of meteorology enables us to go in the matter of weather prediction.

To do this it will be necessary to describe briefly the methods now being used.

In general those who have limited knowledge of the present state of the science seem to be subject to one of two errors—either they expect much more accuracy in the way of weather prediction than is now possible, or they ignore present possibilities which could prove very useful to them.

There is very little doubt that the science of weather is one of mankind's oldest. It affects all human activities so much that even primitive man was forced to give it his attention. During earlier times, however, it was mostly the province of the soothsayer or the astrologer. The numerous proverbs and superstitions about the weather all bear witness to this. On the other hand meteorology was one of the last sciences to receive serious scientific attention. The chief reason for this delay was that the development of meteorology had to wait upon developments in other sciences—in hydrodynamics, in thermodynamics, in radio and other electronic devices—and it might be added that the solution of many problems still awaits the solution of allied problems in these or other fields. At any rate it was not until the middle of the last century, when the development of the telegraph allowed the quick transmission of weather reports, that the first successful attempt was made at weather forecasting. Since that time there has been a more or less steady advance in the science. It is assumed that most readers are familiar with the weather map of 20 to 30 years ago, and only improvements since that time will be enumerated.

The basis of any weather map consists of a series of weather observations made all over the world. By international agreement all these are made at the same hours. On the North American continent, for example, there are about 600 such stations extending from the Northern Arctic to Mexico reporting every six hours and often more frequently than this. These observations consist of such elements as barometric pressure and tendency, wind, temperature, humidity, cloud amount and type, precipitation, and so forth. Then by means of a complicated teletype and radio network these are collected at central points and distributed to all forecasting centers. Except for the more remote stations, this usually is accomplished in about an hour and a half from the observing time. As it is received over the teletype, each observation is plotted on its appropriate station on the weather map. When this is completed, the forecaster is ready to take over. His first step is to locate what might be called the elements controlling the weather. By drawing isobars, or lines of equal barometric pressure, areas of high pressure and areas of low pressure are defined. This is very similar to drawing contour lines on an ordinary map. By drawing lines of equal elevation the hills and valleys will be defined corresponding to our areas of high and low pressure. Isobars tell us which way the air must flow. In electricity the current must flow from high potential to low potential, and the volume of flow or amperage corresponds to the potential gradient. In the atmosphere the wind velocity corresponds to the pressure gradient, however, the direction, due to the effect of the earth's rotation, is not from high to low pressure but along the isobars.

The next elements to be located are not so well known but are equally important. These are fronts. In recent years it has been found that the atmosphere is divided into different masses of air one of which, for example, moving up from the Gulf of

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Mexico may be warm and moist, while another moving down from the Canadian Arctic may be cold and dry. Between these two air masses there usually will be a zone or line across which the temperature or moisture content changes abruptly —discontinuity, in mathematical language. This zone or line is called a front. As a result of the different densities in the two air masses warm air usually is being lifted at these fronts, and condensation is taking place as the pressure decreases. Therefore these fronts are the cause of a large percentage of the bad weather effects that we experience.

When these controlling elements have been located, the next step is to determine the rate and direction in which the centers and fronts are moving and to determine where they will be 12 or 24 hours ahead. If this is known, then what sections will be experiencing good or bad weather at that time should be known. For example the map may show that a cold front lies north–south through Toronto with an area of high pressure over northwestern Ontario. Since these will move past Montreal in the same order, it can be stated that at a certain hour in the future Montreal will be experiencing showers followed by a veering and increasing wind, a drop in temperature, and clearing skies. The time within an hour or so when each of these will happen should be predictable, as well as the amount of change in wind or temperature. This account of the forecast process quite naturally has been highly simplified, and it is just the points which have been omitted that bring the element of uncertainty into the forecast.

This is a point which should be of considerable interest to the engineer—that is, what things can be forecast and what cannot. In popular literature there seems to be two schools of thought on the matter. The older one—perhaps the result of sad experience with forecasts in earlier days—is that the weatherman is always wrong. The second swings to the other extreme and believes that as result of recent developments the modern meteorologist can forecast nearly everything—can even tell you in January whether it will rain Easter Sunday. The last opinion is probably partly the result of certain rosy pictures painted in the popular press which also has given us plastic cars, a helicopter in every back yard, and every man with a $10,000 gadget-run house.

As usual the truth lies between these two extremes. Weather forecasting does not and cannot pretend to be 100 per cent accurate. Though many notable advances have been made in the last 25 years, it is readily admitted that there are many problems and weather phenomena that have not yet received a satisfactory scientific explanation. Until this is done we cannot hope to forecast them on any basis except that of experience, which is not very satisfactory.

Having admitted the darker side of the picture however, one must hasten to add that there is also a brighter side. Developments over the past quarter century have enabled us to go far beyond the older type of forecasts that perhaps read, "Partly cloudy, rain in places." This is particularly true of aviation forecasting, which has received very close attention in the past ten years, but it also applies to many elements affecting the engineer. It might be assumed, first, that it has been possible to foresee all the different changes that will take place on the weather map. This being the case the following can be done:

1. Temperature. The maximum temperature for a day and the general minimum for the night can be forecast within two or three degrees. "General minimum" is used because this temperature often is affected by very local conditions, such as proximity to bodies of water, or location on mountains or in valleys, which cannot be considered in detail in a forecast covering a large district. When these particular details are given, however, there is no reason why a good forecast cannot be made for one particular point. In the case of temperature changes it can be stated within an hour or so when the temperature will begin to rise or fall and the extent of the change.

2. Humidity. Under average conditions humidity can be forecast within about ten per cent in terms of relative humidity or four degrees in terms of dew points.

3. Wind. Moderate or strong winds can be forecast quite accurately both as to direction and speed for an exposed location. If the location is sheltered in any way, however, by hills or trees or other obstacles, the velocity and speed may be very different. In such a case a special study would have to be made of each such point to determine the local effects. The winds mentioned here are general winds which prevail over a large area. In addition there are local winds produced by small storm areas such as thunderstorms or small tornadoes. About the most that can be attempted with such winds is to indicate the possibility that they will occur. There is very little hope that the exact area or time can be named, or that the different wind directions can be foretold fully until the storm has actually developed.

4. Degree of Cloudiness. This usually can be foretold within three-tenths or four-tenths and often much closer. The thickness of the cloud also can be indicated with a good degree of accuracy.

5. General Weather. The time within the next 72 hours when rain or snow should start or stop can be forecast. The total amount of rainfall or snowfall during any storm is somewhat more difficult, but if they are forecast on a basis of light, moderate, or heavy they should be right about 80 per cent of the time.

6. Freezing Rain. To this element, very important to the electrical engineer, the same remarks apply except that this depends also on the temperature forecast, and, when the temperature hovers around 32, this must be quite accurate indeed. Canadian experience has been that in 80–85 per cent of the cases it was possible to provide previous warning of freezing rain or sleet conditions.

7. Thunderstorms. The time when thunderstorms are likely to occur over a certain area can be indicated, but predictions on where individual storms will occur or the paths they will follow cannot be attempted. It may be easier to realize why if one thinks of a thunderstorm as a shot from a gun. One can give warning when the gun is fully loaded and likely to go off, but there are so many small local conditions that may or may not pull the trigger, that it is impossible to say just where the shot will occur. The same can be said of local showers as distinguished from general rainfall.

It will be seen from this account that an accurate forecast of the weather features most important to the engineer can be given over a general area. It must be admitted that there may be local variations from this forecast which it would be impossible to detail without destroying the value of the forecast, but it will be found that this is still a great advance over the present system of operations entailing no knowledge of future weather conditions.

All this has assumed that it has been possible to foresee all developments on the weather map. Most of the time this will be the case, but it is possible that on rare occasions there may be sudden developments which it was difficult to foresee that were not shown on the last weather map. These are usually the cause of the small number of forecasts which are incorrect, and one of the problems which meteorologists now are attempting to solve is how to foresee these sudden developments of new weather areas.

The matter of the range of forecasts is an absorbing one to the engineer and one which is even more important to the meteorologist. To state the case briefly it is the general opinion of meteorologists that no forecast of *reasonable* accuracy yet can be given for a period of more than four or five days, and no *detailed* forecast can be made for more than three days ahead. This problem perhaps has been confusing to those on the outside because of the number of claims advanced in recent years for long-range forecasting systems. In evaluating such systems two facts must be kept in mind. The first is that a straight guess as to the weather on any particular date should be right 50 per cent of the time. If, in making this guess, climatological averages are taken into account, the accuracy should be much better than that. For example, if you wish to know whether it will rain a week from today and if in addition you know that at this time of year it rains one day out of three, then the probability that you will be right if you say it will not rain is almost seven out of ten. Any other system of long-range forecasting must, therefore, be able to exceed this method to be of any real value. It is the considered opinion of those who have investigated most of the newer systems that they

* Present experiments with radar offer some hope that it may be possible to locate and chart the course of local rainstorms.

are no better than the system of climatological averages.

To sum up this article to this point it can be said that present-day meteorology is able to provide fairly accurate forecasts, up to three days ahead, of temperature, humidity, *general* wind direction and velocity, cloudiness, and precipitation, though with the latter the forecast of the actual occurrence is apt to be more accurate than the forecast of amounts. Forecasts of a more general nature up to five days now are being made in the United States, but beyond that period most meterologists feel that climatological statistics still provide the most reliable indication.

The remainder of this article will try to consider the weather problem from the electrical engineer's viewpoint. The effect of the weather on the electrical or power industry would seem to fall into four separate fields:

1. Effect on general outdoor operations.
2. Effect on electric equipment.
3. Effect on consumer demand for power.
4. Effect on water resources of hydroelectric power companies.

GENERAL OUTDOOR OPERATIONS

Both the power companies and the communications companies must carry on considerable outdoor operations at all seasons of the year, particularly on transmission and communication lines. It is hardly necessary to indicate to engineers that such operations are dependent to a great extent upon the weather. The mere fact that most major operations are planned for the months of best weather should indicate this. The weather not only affects the comfort of the employees, but at certain times it makes outdoor activities almost impossible.

The winter snowstorms in Quebec, for example, often result in blocked roads for several days at a time. In general such outdoor activities will be affected by snow or rain, high winds, and low or high temperature. From what has been said previously it will be seen that these factors can be forecast quite satisfactorily for two days ahead. Outdoor operations then can be planned with fair certainty that far in advance. This side of the matter, however, is one of the most familiar, and it is the other effects, which most often are overlooked.

EFFECTS OF WEATHER ON ELECTRIC EQUIPMENT

The effect of weather on electric equipment also should be apparent to the electrical engineer. Perhaps the most noticeable effect here is that on transmission and communication lines. Glaze storms can result in damage running into hundreds of thousands of dollars. In the case of transmission lines some of this damage may be avoided by warming the conductors internally. This very often requires some advance notice, however, especially where it will require rerouting of loads. These measures are not possible on communication lines, but the length of interruptions to service could be reduced greatly, if it were possible to prepare for such storms ahead of hand. The question in the engineer's mind seems to be whether such warnings of a reliable nature can be issued. As has been pointed out earlier, weather science does not pretend to be perfectly accurate at present, but on warnings such as glaze storms a high degree of accuracy can be attained. Generally it can be stated within an hour or two when the glaze can be expected to start, when it is likely to end, its general intensity, and the conditions following the storm, that is, whether it is likely to be followed by rising temperatures—which would cause the ice to melt—or falling temperatures and the strength of the wind following the storm—which can increase the damage by 100 to 200 per cent. It is quite probable that an occasional occurrence may not be foreseen, or that one case forecast may not happen, but this should not occur more than ten per cent of the time, and the general result still will be far ahead of the present method of sitting back and waiting for things to happen.

Mr. Davison of the Ontario Hydro-Electric Power Commission who wrote on this subject last year,[1] has given special attention to another effect of weather on transmission lines—that of galloping conductors. This is a problem requiring not a forecast but a series of meteorological records for analysis of wind gustiness. The same of course applies to the design of transmission lines and the establishment of standards. Sometimes it has even seemed that not sufficient attention has been paid to meteorological records in setting up such standards. In certain sections it almost would seem that the standards exceed what might be expected from meteorological data, whereas in others the reverse is true. During the past ten years, for example, many additional meteorological stations have been established in Canada, especially in the more northerly sections. It is general experience that the more serious sleet or glaze storms are confined to Southern Ontario, the upper St. Lawrence valley, and the Maritimes, and that north of this belt the frequency of such storms is very low. The data to determine this should soon be available, and, if such be the case, it might be a factor in altering present standards.

Lightning is another factor affecting electric equipment. I already have indicated fairly well just how much aid the meteorologist can give in this problem. The general areas in which storms are likely to occur can be indicated, as well as the times in which such storms will occur. These can be indicated as much as 48 hours ahead. The actual location and path of such storms is another problem. It would appear from studies made in other countries that thunderstorms have a tendency to follow certain paths, depending probably on the conductivity and the topography of the ground. No such studies yet have been made in Canada, but valuable knowledge might be gained if they were.

Another point affecting the operation of electric equipment is that of atmospheric humidity. This is perhaps most noticeable in telephone equipment and in the manufacture of insulated cable. The problem here is quite simple from the meteorologist's point of view. Humidity can be forecast to a high degree of accuracy up to 48 hours ahead.

The points which I have mentioned where weather affects electric equipment have been only the most apparent ones and have been mentioned only as examples of what help can be given. There are many other effects, but determining them is actually the task of the engineer and not the meteorologist.

EFFECT ON CONSUMER DEMAND FOR POWER

This is a problem which has received considerable attention from certain utilities in the United States. The demand for power will be influenced by the brightness of the day, and by the "effective temperature." The brightness of the day will depend in turn on the time of year, which governs the maximum altitude of the sun, the visibility or transparency of the atmosphere, and most of all on the cloud cover. It is not sufficient to know the amount of cloud only, but its thickness also must be known. The "effective temperature" is the controlling factor in the demand for power for heating—perhaps not so important in these regions. By "effective temperature" is meant a combination of temperature, wind velocity, and humidity, all of which combine to determine the amount of heat required to heat any given space. The theory then, is that if the distributing company has a reliable forecast of cloud cover, visibility, temperature, wind and humidity its engineers should be able to forecast the variation in power consumption for lighting and heating. To put such forecasts into actual use it would be necessary to make a study of the variation of power consumption under different weather conditions and then to base further forecasts on this past experience.

The procedure mentioned here is not a hypothetical one, but one which has been put into practice by several public utilities in the United States. Very considerable success has been achieved in forecasting power demands for 24 hours ahead. It is notable, however, that to achieve this success these companies found it necessary to employ their own meteorologists and to install teletype drops to the meteorological teletype circuits.

EFFECT ON THE WATER RESOURCES OF HYDROELECTRIC POWER COMPANIES

One of the major concerns of the hydroelectric power companies is the maintenance of sufficient water reserves and the economical use of such reserves. This has been especially important during the past two years when it has been necessary to run near full capacity. Sufficient water reserves must be accumulated during the wetter seasons to carry over the drier parts of the year. At the same time the company will not realize its maximum income, if too much water is being held in reserve when the dry season ends. The same problem applies in short-term management. If the times and amounts of precipitation could be known beforehand, then an equal amount probably could be withdrawn from reserves at a time when the need is probably greatest.

At the present time forecasting can be of only limited help with the first of these problems, which we might call long-term management. What is actually needed is a reliable seasonal forecast which will state, for example, at the beginning of the summer whether precipitation will be above or below normal for the summer season and just when the wet fall weather will start. Although a great deal of attention is being paid to research on long-range forecasting, and in spite of the claims made for a number of systems, it is believed that no satisfactory method of making such forecasts yet exists.

In that case the alternative is to work from climatological records. Such figures will indicate the maximum, minimum, and average precipitation for the drainage area, and it will be necessary for the engineer to calculate on this basis. As a result of the war and the establishment of a large number of extra meteorological reporting stations it can be anticipated that much better precipitation records soon will be available, especially for the more remote sections which previously were poorly covered.

Forecasting can prove of much more assistance in short-term management. Precipitation amounts are rather difficult to forecast, particularly in the case of showers and thunderstorms where the amounts may vary an inch or more in a few miles, but such forecasts still are of sufficient accuracy to make them quite valuable. A forecast of rainfall or snowfall amounts is much more accurate in the case of storms covering large areas, and it is these which produce the major part of the annual total.

The problem of water reserves, however, is not solved even when the precipitation is known. All precipitation will be divided between evaporation and runoff ($P=R+E$) and theoretically before one could determine the runoff from any given amount of precipitation, it would be necessary to determine the evaporation term. Until recently it has been impossible to measure evaporation next to land surfaces. Studies in aerodynamics, however, now have yielded information on the structure and characteristics of the air near the ground, and this is permitting us to develop a technique for measuring evaporation from natural surfaces. When such data becomes available it then should be possible to measure each of the three terms in the hydrologic cycle. Without such data, however, it is still possible to establish an empirical relationship between precipitation and runoff, based on past experience. Though the ratio of the two will depend on a number of factors such as the character and moisture content of the soil, intensity of the rainfall, temperature, the state of vegetation, and so forth, it should be possible to obtain an approximate ratio of the two for an entire drainage area. This ratio of course must be varied to suit changing conditions as previously outlined, and frequently during a heavy storm the runoff factor will vary from hour to hour.

The procedure followed by the United States flood forecasting service might be of interest as an illustration of what is necessary to predict stream levels. In setting up such a forecasting service it first was found necessary to have a complete network of stations reporting precipitation and river stages together with snow and ground-surface conditions, and to provide a comprehensive network of telephone, telegraph, or radio communications to bring these to a central point. These observations then pass into the hands of a competent forecaster who must have expert training in meteorology as well as in flood forecasting. The forecast of future flood stages then is reached by a combination of all available information. This information includes

(*a*). Past precipitation measurements.

(*b*). Present river stage readings.

(*c*). Forecasts of future precipitaton.

(*d*). Data with regard to the runoff coefficient as shown by research and past experience.

The variation of this last factor under many different conditions and types of soil has been the subject of considerable study. In reaching the actual forecast the procedure varies. On the lower reaches of larger rivers the forecast will be based chiefly on readings from gauging stations upstream. In headwater regions the forecaster must go beyond upstream river stages and take account of forecasted rainfall, infiltration capacity of the soil, runoff from melting snow and the physiographic characteristics of his basin. The stream discharge from tributaries whose watersheds have been selected as typical of the entire basin may be used as a guide.

This system probably would prove too expensive to be undertaken by any private corporation, but it contains a number of suggestions on how present methods of water-level prediction could be improved.

Meteorology can be of increasing use to the electrical engineer, if continued effort and study are applied to the matter. I have already outlined what can be done at the present time, but the fact remains that many companies are making only limited use of this knowledge. This may be partly due to a lack of knowledge of the subject on the part of the engineer. The increased use and publicity which meteorology now is receiving, as well as talks of the present nature, should help to remedy this. Other engineers have taken up the subject with expectations which were not warranted by present development of the science. They perhaps have expected that they might receive precipitation forecasts for weeks in advance or be advised ahead of time of all thunderstorms affecting their power systems. That such information cannot be supplied should not mean that the engineer can lose interest in the matter. There is still available a large mass of information which I already have indicated, and a study should be made of the ways this can be applied to his work.

Certain other problems should be made the subject of further study either by the electrical industry or by the Canadian Meteorological Service. The path of thunderstorms in a district is one. The investigation of the matter of cycles is another. Still another is the incidence of glaze storms over certain districts, especially with a view to the topography of the district.

There are also certain improvements which might be made in the service being supplied the electrical engineer. It would be an advantage if there were regular radio broadcasts of expected weather over local stations, such broadcasts to be much more detailed than those now being supplied. In some countries regular snow surveys have been undertaken by the meteorological services. So far in Canada this work has not been organized in a really efficient manner, part being done by private companies and part by other government services whose concern in the matter is rather indirect. An increased staff is required by the Canadian Meteorological Service to serve industrial companies and general forecasting. Most of this service now is being supplied by a staff which was set up to serve aviation alone. A larger staff would be able to supply more frequent and more detailed forecasts and to keep all concerned advised of any sudden developments.

The electrical companies themselves can help to improve the accuracy of forecasts by furnishing the meteorologist with all weather observations made over their own systems. Such an arrangement has been operating for some time between the Canadian Service and the Shawinigan Water and Power Company, and the observations have been of great value in improving the accuracy of forecasts.

If an electrical company is to make full and efficient use of weather information, it should demand that the personnel who are handling this information have a sound knowledge of the basic principles of meteorology, and many United States companies have found that it paid to have an expert on their staffs.

We are very hopeful that a number of improvements will come out of the research being carried on during the present war. Radar might enable quick observations of different layers in the atmosphere. Possibly some of the long-range forecasting systems may be able to prove its worth.

The improvements to be effected by the meteorologists depend to a great extent upon the demand made by those who need their services. Money and personnel must be supplied by the government, and this will be done only in proportion to need shown.

There is no doubt that, given the money and the personnel, the meteorologist could solve many of the weather problems now affecting the electrical engineer.

REFERENCE

1. Meteorological Service for Electric-Power Systems. **A. E. Davison.** *Electrical Engineering*, volume 63, June 1944, page 203–09.

Electrical Essays for Recreation

The following essays are presented for the recreation of the reader. The author's challenge to the reader is: Can you find the error in the reasoning accompanying the various examples?

D-C GENERATOR WITHOUT SLIDING CONTACTS

Figure 1 shows a core with an air gap *B*. A wire *C* is bent into the shape of the letter *U* and placed in the gap as shown. The wire is caused to swing backward and foreward in the air gap. This means that the leads to the wire are flexible but there is no complete rotation that would require a sliding contact as is found in the slip rings of homopolar generators and in the commutators of multipolar generators.

The wire is vibrated so that it crosses the gap with a velocity given by

$$v = V \sin \omega t \tag{1}$$

At the same time the current in the coil wound on the core is varied so that the flux density in the air gap is given by

$$b = B \sin \omega t \tag{2}$$

Now the formula for the voltage induced in a wire cutting a magnetic field is

$$e = bvh \tag{3}$$

where e is the instantaneous voltage, b the flux density, v the velocity, and h the length of the wire in the field. We have on substituting equations 1 and 2 into equation 3

$$e = BVh \sin^2 \omega t \tag{4}$$

Equation 4 can be rewritten, using the trigonometric identity,

$$\sin^2 a = {}^1/_2 - {}^1/_2 \cos 2a \tag{5}$$

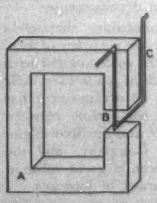

Figure 1

as

$$e = \frac{BVh}{2} - \frac{BVh}{2} \cos 2\omega t \tag{6}$$

A filter similar to that found in the rectifier voltage-supply of a radio set can be connected to the flexible leads and the double-frequency term in equation 6 will be eliminated. This leaves the constant

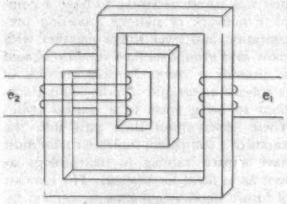

Figure 2

term and we have a direct-current generator using no sliding contacts.

A TWO-TO-ONE VOLTAGE-RATIO TRANSFORMER WITH ONE-TO-ONE TURN RATIO

This transformer is shown schematically in Figure 2. The coils shown have three turns but any number can be used. If both coils have the same number of turns, then neglecting leakage

$$\frac{e_2}{e_1} = 2 \tag{7}$$

This may be shown as follows. Assume that the flux in the core in the coil on the right is ϕ. Then the flux in the coil on the left will be 2ϕ since the core passes through this coil twice. The voltage induced in the right-hand coil is

$$e_1 = N_1 \frac{d\phi}{dt} \tag{8}$$

The voltage induced in the left-hand coil is

$$e_2 = N_2 \frac{d(2\phi)}{dt} = 2N_2 \frac{d\phi}{dt} \tag{9}$$

Therefore if $N_1 = N_2$

$$\frac{e_2}{e_1} = 2 \tag{10}$$

as stated herein.

POWER-FACTOR PARADOX

Consider the ten-ampere current wave shown in Figure 3a. The amplitude is 14.14 amperes. Suppose that a rectifier is used to pass the upper half of the sine wave as shown in Figure 3b. The effective current is now five amperes. If this current is passed through a one ohm resistor the power computed from the formula

$$p = Ri^2 \tag{11}$$

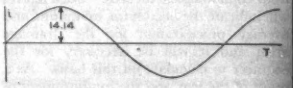

Figure 3a

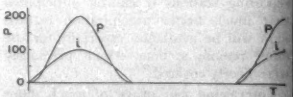

Figure 3b

will be a wave as indicated in Figure 3b. It has a maximum equal to 200 watts and a minimum equal to zero. The power wave is a double-frequency sine wave displaced from the axis by an amount equal to the amplitude. Therefore the average value of the power wave is 100 watts. Since there is no current half of the time the true average power is only 50 watts.

The effective current is five amperes. This passing through a one-ohm resistance produces an effective voltage drop of five volts. Therefore the volt-amperes for the circuit is 25, the power is 50 watts, hence the power-factor is 2.

HARRY SOHON (A'28, M'43)
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Scientific Truths and Their Use by Society

FREDRICK T. ADDICOTT

This article clarifies the responsibility of the scientist and engineer in the modern world, and emphasizes the obligations of society to utilize the researches of science for the common good.

CRITICISM frequently has been raised that scientists and engineers are as much responsible for the evils of civilization and the horrors of war as they are for the good arising from their contributions to our present state of technical advancement. The implication of this criticism is that they should either limit the breadth of their activities or guide the application of their work so that the results could not possibly be misused. The object of this article is to make two points:

1. There is no valid basis for such criticisms.

2. A scientist has certain obligations which, if met, discharge his responsibilities to society.

The fallacy of the idea that a scientist or engineer might be able to predetermine all of the ultimate uses to which the results of his efforts might be put is self-evident. In addition, it could be argued extensively and successfully that the good arising from the results of scientific effort has far exceeded the evil. But in a larger sense science is responsible for neither. The principal concern of science is to add to our knowledge. It should not be considered primarily responsible for the use society makes of that knowledge. Engineers show how scientific achievements may be applied, and likewise engineers cannot be held responsible when society directs these applications into destructive channels. Ultimately it is the option of society to approve or reject the utilization of scientific advancements. Many cases are on record in which society has permitted the withholding of technical developments, even though they were of obvious benefit. Is it not then equally the option and obligation of society to reject such applications as would appear detrimental to the common good?

The duty of the scientist is to search for truth disinterestedly and to present his findings without prejudice. The duty of the engineer is to devise useful applications of these scientific findings. (Many scientists and engineers perform both functions.) One of the principal duties of the students of social problems should be to examine and recommend the best utilization of the advancements of science. Such a division of responsibility is inherent in the complexity of this civilization. An advance of real worth may require the close co-operation and undivided attention of many scientists and engineers. The achievement of maximum benefits from an outstanding discovery, however, requires, in addition, the full co-operation of those concerned with social problems. The final responsibility for the ends to which knowledge is utilized rests upon this latter group, and not upon the scientists who discover truth or the engineers who show its applications.

This division of duties does not mean that the scientist and the engineer are free to ignore their fellow men in the pursuit of their technical interests; they have obligations to their calling and to society which cannot be ignored.

First and most important is the obligation to adhere to the scientific method. One should never let the value of his fine training be dissipated by permitting scientific principles to come second to personal impulse. The scientist or engineer must constantly re-examine himself and his work, and keep both in line with the most rigorous scientific precepts. Only by so doing can he be sure that his efforts will result in real and lasting contributions.

Second, the scientist or engineer must conscientiously instruct those who come under his tutelage, whether they be students or associates. Instruction should be given in the scientific method as well as in established knowledge. It is essential to the maintenance of the present civilization and to future progress that the scientific method be passed on to the coming generations. As new facts become known the worker in a scientific field should add them to his personal store of knowledge, then these facts should be sifted carefully and passed on to students and associates so that they may have a sound foundation upon which to build the advancements that accrue in their lifetimes.

Third, the scientist and especially the engineer have the obligation to indicate clearly to society what good they believe might be achieved from their contributions. This is an obligation which should not be overlooked. Although the needs of society are not fully known, something is known of the possible value of the work of the scientist and the engineer, and where possible the first steps should be taken towards its full utilization.

It is possible that many would wish to modify these suggestions. It might be valuable to amplify or extend them. However, if this brief discussion stimulates the reader to consider his relations to society and the obligations they impose, the writing of this note will have been well justified. If the scientist and the engineer should acknowledge these three obligations:

1. To rigorously adhere to the scientific method.

2. To instruct conscientiously those who come under their guidance.

3. To indicate clearly to society what benefits might accrue from their contributions.

and conscientiously attempt to fulfill them, they are worthy of a respected place in society. After the engineer or scientist has done his part, it is the duty of those who guide society to see that means are available for the utilization of the achievements of science and engineering for the highest good.

Based on article, "The Obligations of a Scientist" published in *Science*, September 22, 1944.

Fredrick T. Addicott is assistant professor of botany at the Santa Barbara College of the University of California, Santa Barbara, Calif.

Engineer's Role in Postwar World

THE sales engineer is the man of the hour—so concluded L. C. Welch, a director and general manager, lubricating and sales technical-service departments of the Standard Oil Company of Indiana, in an address recently delivered before the Engineering Society of Detroit Rackham Education Memorial. Mr. Welch's topic was "Engineering Salesmanship and Engineering Training" in which he developed the role of the graduate engineer from the days when he was a highly technical man with little or no interest in selling himself or any product to the advent of the engineering era and the industrial advance of the postwar years.

Mr. Welch predicted that the engineer salesman will become a necessity in many industries in the world of the future; that many industrial concerns, in an effort to develop rapidly capable talent of this character will initiate, reinstate, or extend training courses where selected graduate engineers, with and without sales experience, will receive intensified instruction, combining laboratory and theoretical training, with practical application in plant, factory, and refinery. The men necessary to meet the demands of the future will be found among the well-grounded well-qualified sales engineers, trained in basic engineering, and in the understanding of technical and practical problems of customers.

A Survey of Co-operative Councils

FRANK E. SANFORD
MEMBER AIEE

FORMATION of local councils of engineering, technical, architectural, and scientific societies is a movement that is rapidly gaining strength across the country. Provision of a medium for co-operative action among local sections of national societies and local clubs or societies of engineers is the principal purpose of these council organizations. New individual memberships are not involved, but members of all constituent groups are members of the council through affiliation of their organization.

Local conditions and purposes have governed the arrangements made, and in general there has been no outline or guidance on a national scale. Local committees planning councils have often sought some suggestions from a few other cities but, so far as we have been able to learn, no general review has been made of the various arrangements in use. The Cincinnati Council sponsored this survey of co-operative plans in other cities, in recognition of its own tenth year of operation.

Our broad purpose is to make available to other similar groups, the suggestions and encouragement that such a review may bring as well as to seek possible ideas for extensions or improvements in our own plan. Knowledge of the plans and experiences of others may be helpful to those who are starting and experimenting. It may also be an inspiration to still other groups to start, or to expand co-operative arrangements.

This historical sketch of the growth of local councils of engineering and technical societies brings developments of the movement up to date. In this review the author gives some valuable information on the present status of these councils in the United States, and encourages scientific men to formulate co-operative plans and arrangements for the interchange of their highly specialized knowledge and the spreading of technological advances.

SCOPE OF ORGANIZATIONS

Information from 35 local organizations has been reviewed in this survey. About 400 local sections and societies and 100,000 individual members are represented in the councils or affiliate arrangements.

Four of these co-operative council plans have been in operation 25 years or more. Six more were added by 1930, 11 in the period 1934 to 1939, and ten since 1940. Of the latter, five councils were started last year. Four additional councils are now being organized.

Since the primary purpose of this report is to present ideas that may be helpful and suggestive, some of the outstanding activities have been noted rather than details of each council. A tabulation of size, member organizations, and other data was prepared, but it does not appear as useful as the more pertinent information derived from a review on this broader basis.

Two Founder societies, AIEE and the American Society of Mechanical Engineers, are in every council of the survey, with a third, American Society of Civil Engineers, missing in only five cases. A professional engineers' society, most frequently a chapter of National Society Professional Engineers, is listed in two thirds of the reports.

Excepting in four cities, the average council includes ten member societies—four with 15 to 17 members, four with five or six, and the majority with 8 to 12 societies. Cleveland and Chicago with 33 societies, Detroit with 28, and Pittsburgh with 25, cover a much broader scope of organization than this average.

OUTLINE OF PURPOSES

Co-operative action by the member societies on matters which are beyond the scope of the individual organizations is the primary purpose stated. A means is provided on a broad scale to promote the public welfare whenever technical, engineering, and scientific knowledge and experience are involved or can be useful.

Another definition states, "for co-operative effort in increasing the scope and availability of the individual organizations; to promote, co-ordinate, and integrate inter-organization activities and good-will; to publish a bulletin; to encourage interest and participation in civic affairs."

Provisions are made for: vocational guidance for technical students, co-ordination of program activities, encouragement of joint meetings between two or more societies. Annual joint meetings of all societies are arranged by several councils. Co-ordination is a stated purpose, but there is no direct jurisdiction over the meetings or actions of the constituent societies.

Several councils have been organized in connection with, or as a result of, war activities. Two council reports state that "the organization is a natural development from the organization of societies which sponsored the War Production Clinic." Another followed a temporary arrangement to consider postwar planning problems. It was felt desirable that the engineers be represented in future action and be organized to offer their assistance and advice in the solution of such problems.

PLANS OF ORGANIZATION

In all of the council plans reviewed, the affairs are administered by two representatives or delegates, or by one delegate and an alternate, from each society. They are usually regular officers of the member society or, in a few cases, they are appointed for the council. Meetings of the council, governing committee, or board are held three or four times each year, or annually and as called by the chairman.

Perhaps the organization plans can be classified into three broad groups or types, although the lines of separation in type are not sharp.

1. A local engineers club or society sponsors local section affiliation or participation in a council. Joint memberships are encouraged by several local societies, by a reduction in dues for members of affiliated societies.

2. Local sections have organized the council, usually with a local club participating as one of the members.

3. A combination of the two plans appears in a few cases, including our Cincinnati Council. The local society and local sections of national societies are members of the council, with the local society performing certain services for the council.

NOTES OF ACTIVITIES

The following notes of activities may not do justice to many of the councils. The aim has been to select an outstanding point about each, and in this I could easily be in error because of lack of familiarity with the individual group.

Since 1916, The Engineers' Club of Baltimore has sponsored a plan of affiliation, providing local headquarters, meeting rooms, and services for which each society pays annual dues for its members who are not also members of the club. A closely knit association has resulted for interest in civic and technical matters in the city.

Joint Council of the Associated Engineering Societies of St. Louis is composed of representatives from the Engineers' Club of St. Louis and from each local section of a national engineering society holding membership in the council. Joint Council has, since 1914, taken an active interest in civic affairs such as furnishing aggressive assistance in the formation and adoption of a new smoke ordi-

Essential substance of an article in *The Engineer and Scientist*, April 16, 1945.

Frank E. Sanford is distribution engineer, the Cincinnati Gas and Electric Company, Cincinnati, Ohio, and is director for publications, The Technical and Scientific Council of Cincinnati.

nance, framing examinations for civil service, writing a new building code, and in recommending appointments to prominent technical positions. They do not have a publication or joint notice for societies' meetings.

Affiliated Technical Societies of Boston, organized in 1922, has grown from 9 to 15 affiliated societies and is now organized as the Engineering Societies of New England. Co-operating also are 8 allied organizations in other cities. An outstanding activity is industrial co-operation with various manufacturers' associations and Chambers of Commerce in the area. Other committees are to provide counsel and assistance for young engineers, for public affairs and for employment service. Outstanding engineers are recognized by an annual New England Award. A weekly paper carries notices of all affiliated society meetings.

A record of civic and professional affairs interest that seems to be unsurpassed by any other council appears in the reports of the Connecticut Technical Council (New Haven). The state engineering registration board, appointed by the governor, is largely from the recommendations of council. Several other commissions and board appointments where engineering qualifications are desirable are similarly made from lists submitted by the council. Programs of vocational guidance, civic planning, and co-operation with war-industry conferences have received active attention. Publication of a bulletin has recently been started, with distribution to members of all societies.

The Florida Engineering Council has representatives of the Florida Engineering Society and of local sections and local organizations to act as a co-ordinating committee for all engineers and for engineering problems of the state.

Four local engineers clubs, two state associations, and three local sections of national societies co-operate in the Minnesota Federation of Engineering Societies. This state-wide organization, with headquarters in St. Paul, has taken an active interest in bond issues, and codes, and in submitting lists of qualified members to state boards.

The Worcester Engineering Society is made up of six affiliated societies, who have voted their entire membership into the society. By such action, the affiliate "shall not forfeit its own individual identity and it shall continue to follow its own methods of action. . . ." Individual memberships are also provided in the society for those who are not members of an affiliated society.

Local sections of four national technical societies are affiliated with the Rochester Engineering Society. The club rooms are furnished for meetings, and secretarial and office service are provided for business affairs of all societies. The *Rochester Engineer* is sent monthly to all members of the societies, and the cost for all services is on a per member basis.

A somewhat similar plan is followed by the Providence Engineering Society. Each technical organization may hold its meeting in the society's auditorium, and a weekly meeting announcement bulletin is sent to all members of all affiliated societies. The chairman of each local section meets with the Engineering Society Council.

The Engineers' Club of Birmingham furnishes office service for technical societies in the Engineering Council. Separate notices of society meetings are mailed by the club office. The chairman of Engineering Council serves on the board of the club.

Organized in 1943, The Chicago Technical Societies Council would seem to have undisputed place as the largest organization of this kind. It grew from a temporary committee to assist in the WPB War Production Clinic, and it now has 33 societies with 16,000 members. A monthly calendar of all meetings is sent to all members.

The Cleveland Technical Societies Council publishes *Cleveland Engineering* for its 33 member societies. This weekly was formerly the publication of The Cleveland Engineering Society, a member of council. It carries notices of all meetings to 10,000 individual members of the societies.

Annual joint meetings of all the member societies are important features of several councils, and other joint meetings of two or more societies are frequently arranged in most councils.

Seven joint or general meetings were held in the past year by the Schenectady Engineering Council. This group also has committees active in technical and vocational education and community planning.

Colorado Engineering Council (Denver) celebrated its 25th anniversary at its annual reunion in December 1944. A committee is now preparing a history and review of its activities.

Three joint general meetings, each sponsored by a member society, are a feature of The Toledo Technical Council. At a recent council general meeting there were 600 engineers and architects present of a combined membership of 900. A novel arrangement is the publication in a local newspaper of a column of council society news and notices.

An annual dinner meeting of Oregon Technical Council (Portland) was discontinued during the war. Plans of the Affiliated Engineering and Allied Societies in Ontario (Toronto) to hold an annual joint meeting of all societies were delayed by the war.

Ten annual joint general meetings with speakers of national prominence have marked the years of our Cincinnati Council. Our weekly publication serves as a medium for announcing programs to all of the individual members of societies in council and an annual directory lists all committees and a roster of members. The Engineering Society is publishing agent and maintains the membership and financial records.

Three cities in Indiana have councils. Co-operation of three local sections in several activities led to formation of The Engineers' Club of the St. Joseph Valley in South Bend. They are active in post-war planning, in an airport location and are now planning an industrial exhibit. A monthly magazine goes to all members of the co-operating societies. Local sections of four societies co-operate with the Fort Wayne Engineers Club in a civic affairs committee. Their *Engineers' News* is one of the best papers sent to me in this survey. Co-ordination and secretarial services for the Indianapolis Technical Societies Council are furnished by the Chamber of Commerce Industrial Branch. A monthly bulletin to be sent to all members is planned by this newly organized group.

Several large industrial centers have similar local society affiliation arrangements to facilitate co-operation in matters of common interest. The Engineering Society of Detroit and the Engineers' Society of Western Pennsylvania in Pittsburgh, each publish a calendar of affiliated technical society meetings and have arrangements for use of their auditoriums by these societies.

In Philadelphia, the Engineers' Club co-operates with local sections through an Affiliated Societies Council. The Engineers' Society of Milwaukee has plans for greatly expanding its own activities and is working toward a closer affiliation arrangement with other local societies.

The weekly publication of the Technical Club of Dallas carries all meeting notices to members of local sections affiliated with the club. Each society pays the cost of mailing for its members.

Local sections in San Francisco have an Engineering Council, with many features similar to the arrangements in Cincinnati. The District of Columbia Council is not as actively organized but it is ready to report on any question referred to it by a member organization. A joint notice bulletin was formerly published, but was discontinued several years ago.

The Louisville *Engineer and Scientist* was started on its publication schedule in December 1944. Ten member societies comprise the original group in the Council. The start they have made should be an inspiration to every similar group.

Two other widely separated groups are at similar stages of council development. The Puget Sound Council in Seattle and the Columbus Technical Council are aiming toward co-operative action. Columbus expects to start its publication in May.

A committee representing nine societies is planning for a reorganization of the Engineering Foundation of Buffalo to be more along lines of other council arrangements. A council is being organized in Kansas City. A monthly calendar sheet is to be sent with regular meeting notices of member societies until a bulletin can be

arranged. The Engineers' Club of Tulsa is planning an affiliated council and expects that this review may be an added incentive in their efforts.

A constitution is ready for adoption by the local sections and the Engineers' Club of Dayton. This is along lines of the Cleveland and Cincinnati plans. A joint publication is expected as an early activity.

PUBLICATIONS

Publication of a monthly or weekly bulletin or magazine is one of the most desirable regular activies of a council. Regardless of the extent of other aims and objectives, it is essential that news and information of local interest to engineers should be carried to all the members in the local societies.

Monthly publications are used in a majority of the cases reviewed. A calendar of meeting and program announcements may be included, but apparently this medium is not as widely used as it might be. One or two reports noted that notices were sent out to their members by the individual societies, in addition to the notice in the publication.

Weekly publications, as in Cleveland, Cincinnati, Providence, and some others, serve for the meeting notices. In a number of the cities, the council publication is sent only to officers who are interested in co-ordinating activities, but interest in a general paper is indicated by several reports where this is now the practice.

Advertising is included in about half the publications received in this survey. This is notably true in Chicago, Cleveland, and Schenectady, where it is stated that the Council has no publication expense. Louisville expects to reach a self-sustaining basis also. Costs per member for other publications are noted at 40 or 50 cents per year for both weekly papers and the larger monthly magazines. These subscriptions are apparently always paid by the local section as its cost in the council.

In this connection, it should be noted that there is no better advertising medium to reach the engineers, architects, and specification writers of a local area than that afforded by a small local-interest publication. Equipment, tools, supplies, materials and services are being requisitioned or purchased daily by a large percentage of engineering-publication readers.

ACKNOWLEDGMENT

This very brief review is based on much more complete information received from the chairman or secretary of each group, and it was possible only because of their interest and help. To them we extend thanks and best wishes. Copies of this issue of *The Engineer and Scientist* are being sent to all the contributors, and additional copies are available for further distribution to committee members of societies and councils who may be interested.

The national boards of societies co-operating in the Engineers Council for Professional Development have endorsed proposals for joint activity of local units. The ECPD pamphlet "Will You Help?" points to a future possibility for broader co-operation. They clearly recognize that further development for joint action depends on local growth, and we hope that this survey may be helpful to them.

Locating the right men to furnish the desired information proved rather difficult in some cities. Thanks for help in this direction are due Charles Lee and P. L. Alger and several local Section secretaries of AIEE.

Large Generator for Power Station in Switzerland

View of the stator laminations of a large generator, constructed by Brown Boveri and Company, Ltd., for the Ruppers-wil - Auenstein Power Station, through an opening in the stator frame.

Statistical Methods in Quality Control

III. Frequency Distribution for Setup Check of Process

Quickest method for checking parts within desired quality range, the various operations of the inspector, and the purpose of the obtainable data are discussed in this article.

WHEN a machine is first set up, or a process adjusted, to produce parts of a desired quality, it is necessary to make a quick check of the parts being produced to determine if they are within the quality range desired. It has been found that the "frequency distribution" offers the quickest method of making this check.

A relatively large sample of the parts being produced is taken. It is not necessary that the individual parts be taken in order of production, although this is desirable. However, it is absolutely necessary that all of the pieces in the sample be taken at essentially the same time, that is,

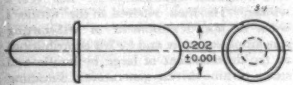

Figure 1. Phosphor-bronze rivet made at the rate of 120 per hour

there must not be any break in production and no pieces must be left out of the sample.

The size of the sample will vary with various factors such as:

1. Difficulty of making the inspection.
2. Length of production cycle for each part.
3. Precision of the tools making the parts.

A sample of 100 pieces is about as large a sample as need be taken, and it is suggested that this be the size of sample taken, when practicable. It is rather important not to spread the time during which the sample is produced over too long a period. However, experience shows that a sample of from 25 to 50 pieces generally gives the data required for this initial analysis.

After the sample has been accumulated, the parts are inspected for the characteristics to be controlled. These might be dimensions, hardness, grain structure, color, or any other of the characteristics determining the quality of the parts. The parts may be inspected by the method of attributes, or of variables, as explained in a preceding article in this series.[1]

Briefly, inspection by the method of attributes means the classification of parts as good or bad. The measure of quality here is the "fraction defective"—the ratio of defective parts to total parts—and inspection by the method of variables means that the various characteristics to be controlled are measured, so that there is an absolute value of the quality of each characteristic. It is by the method of variables that the information is accumulated for making a proper frequency distribution of the particular characteristics in which the inspector is interested. A different distribution is made for each characteristic.

Consider the part shown in Figure 1. The machine has been adjusted by the machine setter to produce these parts within the required tolerances. The inspector approaches the machine and takes a sample of 50 parts produced one after the other. He makes sure that no parts, however obviously defective, are thrown away, except such parts as result from the end of the bar, and, therefore, are not considered normal production. The inspector then measures the diameter of the parts and records the data, as shown in Figure 2. This shows that the machine is producing parts over a wide range with a tendency to produce more parts near the lower specification limit. In this case this wide range might be due to an improperly ground tool or fouling of the cutting edge.

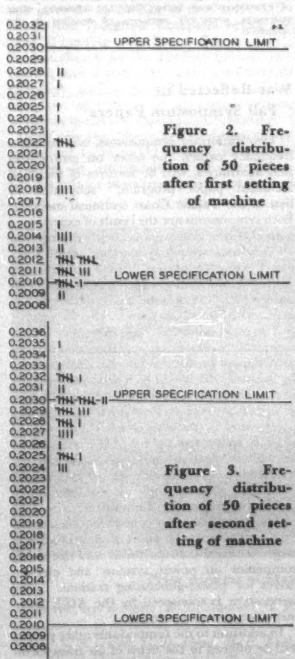

Figure 2. Frequency distribution of 50 pieces after first setting of machine

Figure 3. Frequency distribution of 50 pieces after second setting of machine

The tools must be sharpened and the cutting edges improved, so as to minimize the variability from part to part, that is, to decrease the band spread or range of the parts as produced. The information

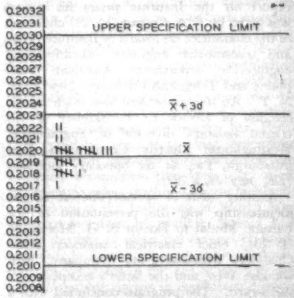

Figure 4. Frequency distribution and control chart after third setting of machine

is furnished the tool-setter and he regrinds the cutting tools and resets the machine, after which another sample of 50 parts is taken and the parts again inspected. The data are recorded in Figure 3.

This shows that the range has been reduced, that is, the variability from part to part is less than formerly. However, the tools are set toward the upper specification limit and parts are being produced which are too large. Tools are readjusted to bring the center of the distribution nearer the center of the specification limits.

The result, in the form of better operating conditions, is shown in Figure 4, based on a sample of 30 pieces. This indicates the operating condition of the machine at the time and proves the machine setup.

Once having obtained these data, it is possible to establish a continuing control of the job by means of the control chart, to be discussed in subsequent articles.

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1. Two Kinds of Measurement—Variables and Attributes. *Electrical Engineering*, volume 64, July 1945, pages 249–50.

2. Control Chart Method of Controlling Quality During Production ASA-Z 1.3 American Standards Association, 1942, New York, N. Y.

One of a series of articles prepared in the AIEE subcommittee on educational activities and sponsored by the AIEE subcommittee on statistical methods.

Personnel of the AIEE subcommittee on educational activities: J. Manuele, H. F. Dodge, A. I. Peterson, and R. E. Wareham.

INSTITUTE ACTIVITIES

Annual AIEE Meeting Held in New York— Items of Interest to Members

Because of the cancellation of the regular summer technical meeting the annual meeting of the AIEE was held in New York, N. Y., on June 27, 1945. Included on the agenda were the report of the board of directors by H. H. Henline (F '43), secretary, and the report of the treasurer, W. I. Slichter (F '12); also reports of the committee on tellers on votes for the proposed amendments to the constitution. Then followed the introduction of and presentation of the President's badge to Doctor W. E. Wickenden (F '39) and the latter's response. A report on the Institute prizes for papers was given by F. A. Cowan (M '29) chairman of the committee on award of Institute prizes and transmission engineer, operation and engineering department, American Telephone and Telegraph Company, New York, N. Y. An announcement was made of the election of Doctor C. E. Skinner (F '12) retired assistant director of engineering, Westinghouse Electric Corporation, East Pittsburgh, Pa., as an honorary member. (*EE, July '45, p 271*).

Another item of special interest to the membership was the presentation of the Lamme Medal to Doctor S. H. Mortensen (F '20), chief electrical engineer, Allis-Chalmers Manufacturing Company, Milwaukee, Wis., and the latter's acceptance of the award. The program concluded with a review of the year's activities of the Institute by C. A. Powel (F '41), president.

The amendments to the Constitution were favorably voted upon by the membership. Hence, the following changes have been authorized.

1. Delete the word "national" from the titles of officers and the names of committees and meetings wherever that word is so used in the Constitution.

2. A Fellow shall be not less than 32 years old and shall qualify under one or more of paragraphs (*a*) to (*e*) of this section. To qualify under paragraphs (*a*), (*b*), or (*c*) he shall have been in good standing in the grade of Member for a period of at least five years immediately preceding the date of application for the grade of Fellow.

(*a*). An electrical engineer by profession. As such he shall be qualified to design and to take responsible charge of important electrical work; he shall have been in the active practice of his profession for at least ten years, and shall have had responsible charge of important electrical work for at least three years. When the applicant holds, in a principal national society of an allied branch of engineering, membership of a grade for which the qualifications indicate a standing equal to that required for the grade of Fellow herein, such membership shall be considered equivalent to five of the requisite ten years of active practice of the electrical profession.

(*b*). A professor of electrical engineering or of electrical science. As such he shall have attained special distinction as an expounder of the principles of electrical science and of electrical engineering; he shall have had at least ten years' experience as a teacher of electrical subjects, and shall have had responsible charge for three years, in an electrical course of a principal school of engineering. Any years of experience as defined in paragraph (*a*) that the applicant may have had as an electrical engineer shall be considered the equivalent of the same number of years of experience as "a teacher of electrical subjects."

(*c*). A person regularly engaged in electrical work for at least ten years, who by training, experience, and proficiency in electrical practice or theory has attained a standing in the profession equivalent to that required for Fellows under paragraph (*a*) or (*b*).

(*d*). A person who has done notable original work in electrical science of a character to give him a recognized standing equivalent to that required for Fellows under paragraph (*a*) or (*b*).

(*e*). A person who holds in a principal national electrical engineering society of some other country membership of a grade for which the qualifications indicate a standing equivalent to that required for the grade of Fellow under paragraph (*a*) or (*b*).

3. Change Article III by deleting the words "professional engineers of standing" and by substituting the words "engineers of standing in the profession." The last paragraph of Section 10 will then read:

Should an applicant for admission or transfer certify that he is not personally known to the above specified number of Fellows, Members, or Associates who are sufficiently familiar with the applicant's experience to justify him in using their names as references, the Board of Examiners may accept, for the deficiency, other references, preferably engineers of standing in the profession.

War Reflected in Fall Symposium Papers

Two important symposiums, one on high-frequency cables, the other on central-station auxiliaries, will be features of the "fall technical paper program," scheduled in lieu of the Pacific Coast technical meeting. Both symposiums are the result of experiences gained from conferences held during the 1945 winter technical meeting, which indicated extensive interest in these subjects and collected information which is considered valuable enough to become a part of the permanent record in AIEE *Transactions*.

The symposium on high-frequency cables represents a gathering together of 17 technical papers and four summaries of discussions by authors who have taken a prominent part in the theory, development, and manufacture of high-frequency cables which were greatly accelerated by the war effort. The symposium is sponsored by the AIEE committee on communication and was arranged by Lieutenant Commander John H. Neher, chairman, Army–Navy Radio-Frequency Cable Co-ordinating Committee.

The symposium on central-station auxiliaries will present the point of view of several large electrical manufacturers and operating companies on power systems and electric drives for power-generating stations. This symposium is sponsored by the AIEE committee on power generation.

In addition to the symposiums other papers will be offered in the fields of air transportation, power transmission and distribution, protective devices, industrial power applications, and electric machinery. Abstracts of the papers will appear in subsequent issues of *Electrical Engineering*, and an announcement of the complete program will be mailed to all AIEE members in September.

Lamme Medalist Reviews A-C Design Work

In presenting the Lamme Medal to Soren H. Mortensen, doctor of engineering, at the AIEE annual meeting on June 27, 1945, R. S. Fleshiem, manager of the electrical department of the Allis-Chalmers Manufacturing Company, Milwaukee, Wis., said that "achievement," inscribed on the medal, carried a special significance for this year's winner. He then referred to the winner's work in the development of self-starting synchronous motors and for his contributions to the development of large hydraulic and steam-turbine-driven generators. Summing up, Mr. Fleshiem said that this year's winner of the Lamme Medal was outstanding in the field of self-starting synchronous motors, large salient-pole machines, ventilation of motors and generators, amortisseur windings, coil design, large air- or hydrogen-cooled turbogenerators, turborotor ventilating systems, hydrogen seal, and lead construction. Furthermore, his extensive contributions in the field of technical writing included his well-known work, "Electrical Machine Design," and the section, "Alternating Current Generators and Motors," in the 1941 edition of the McGraw-Hill "Standard Handbook for Electrical Engineers." Doctor Mortensen's personal service to AIEE was then extolled especially for his work on various committees and for his many illuminating articles and papers.

In accepting the Lamme Medal for 1944, Doctor Mortensen said he realized that the award was not a recognition of his personal efforts but rather of the accomplishments of the Allis-Chalmers Manufacturing Company and those of its engineers in the electrical field. Carrying his listeners back to the turn of the century he told of his joining the trek of European engineers who migrated to the United States to enlarge their horizons by contact with some of its brilliant engineers. He said that two big events in his life occurred when he joined the AIEE and when he was made assistant to R. B. Williamson who was in charge of a-c design at the Allis-Chalmers Manufacturing Company. Touching upon some of his experiences as a machine designer during four decades, he then paid tribute to the AIEE for its help and inspiration, and to his coworkers and colleagues, and especially, the men under whose guidance the electrical department of Allis-Chalmers Manufacturing Company grew. Specifically he mentioned among others R. S. Fleshiem "under whose cheerful guidance and direction the major part of my work in this field was accomplished and for his gracious words spoken in my behalf today, I extend humble and grateful appreciation."

Engineers Council Promoted by Houston Section

The AIEE Houston Section has been instrumental in effecting the formation of the Engineers Council of Houston, Texas. The Section is represented in the council by H. P. Heafer (M '35) division plant engineer, Southwestern Bell Telephone Company, and a past chairman, and S. C. Commander (M '36) sales department, Joslyn Southwest Company and chairman.

The object of the council shall be:

1. To further the public welfare wherever technical and engineering knowledge and experience are involved.
2. To promote co-operation among the engineering societies.
3. To consider and act upon matters of mutual concern to the engineering and allied technical professions.

Ten societies or chapters of national societies are participating in the council. It represents more than 3,000 engineers, architects, chemists, and other technical specialists in the Houston area.

Arrowhead Subsection, Duluth, Established

Following several weeks of intensive work by two national members aided by other interested engineers the Minnesota Section, AIEE, has established the Arrowhead Subsection in Duluth, Minn. Because of time and transportation problems few of the engineers in the vicinity of the Great Lakes had been able to attend the regular Section meetings in Minneapolis or St. Paul. With the assurance that out-of-town speakers who were scheduled to speak at regular Section meetings in the Minneapolis–St. Paul area would also speak to a Subsection group in Duluth, it was possible to prove to the national members contacted that meetings would be assured if a sufficient number of interested engineers would attend.

An organization meeting was attended by 85 prospects who heard an out-of-town speaker. At the meeting Hubbell Carpenter (A '41) engineer with the Minnesota Power and Light Company was elected chairman and R. H. Holmes (A '45) affiliated with the same company, secretary-treasurer. Approximately 60 men signed applications for local members at this meeting. During the year the Subsection had seven meetings at which there was an average attendance of 94.

Technical Groups Formed in Southern District

The technical group committee of the East Tennessee Section has announced the formation of four technical groups in Knoxville and one technical group in Chattanooga. This Section is the first one in the Southern District to use the technical-group idea. The groups with their leaders are as follows:

Knoxville	Electronics	R. M. Alspaugh (M '41)
Knoxville	Industrial power equipment	G. N. Hughes (M '43)
Knoxville	Power generation	L. R. Sellers (M '44)
Knoxville	Power transmission and distribution	H. H. Long (A '30)
Chattanooga	Electronics	E. S. Staples, M. C. Charles (M '41)

In the initiation of the program, both the Knoxville and the Chattanooga areas individually checked their memberships to ascertain what subjects were of interest and the extent of this interest. The results of this questionnaire were used as a basis for determining the organization of the discussion groups.

Fourteen meetings in all were held as of May 1 with four additional meetings during May. The average attendance at all meetings was approximately 11. The meetings brought forth considerable discussion which served not only to increase the knowledge and widen the viewpoint of the participants along the lines of the discussion, but also served as a medium to develop closer personal acquaintance among those interested in the same subjects. All the group leaders worked diligently to make the group discussions successful. Among them should be mentioned M. S. Merritt, chairman, and Messrs. E. B. Doocey, R. A. Hopkins, J. E. Housley, E. E. Jones, R. W. McEver, J. C. Tarboux, C. E. Tarwater, Mead Warren, Jr., and T. D. Talmage.

Work and Play Program at Seattle

"Fun with Science" was the subject of a talk given by C. N. Key of the Pacific Telephone and Telegraph Company before the May 22 meeting of the Seattle Section AIEE; Section officers for the 1945–46 period were elected, and a good time was enjoyed by all members and nonmembers who carried away an assortment of attendance prizes, as shown in the accompanying illustration.

Last year the Seattle Section began the issuance of lapel-pocket identification cards to those in attendance at the meetings—white cards for members of the Institute, and yellow cards for nonmembers. This gave an exact count of the attendance, and the nonmember cards were turned over to the membership committee for further investigation. The white cards for the entire season were carefully saved by the attendance chairman and were gathered together for the May 22 meeting. The winners had to be present to win. In this spirit of jollity and good fellowship the Seattle meetings were adjourned for the season.

Dayton Section Hears Talk on Audible Signaling

"Audible Signaling for the Armed Services" was the subject of an address given by Edward S. Ruth (M '36) chief engineer of Edwards and Company, Inc., Norwalk, Conn., before a recent meeting of the Dayton Section of the AIEE.

Mr. Ruth explained in detail the work of a committee organized in May 1932 following a proposal of the Acoustical Society of America to the American Standards Association for standards of terminology units, scales, and methods of measurement in the field of acoustics. This committee established standards to define numerical scales and other essentials for measuring the loudness and intensity of sounds. A number of investigations was made and the results, Mr. Ruth said, could be taken as the best indications of the present material with, however, the necessary recognition that they may need modification when further data are obtained.

Previous to the beginning of World War II manufacturers of audible signals had never thought of using the decibel or loudness unit in connection with their products. The specifications of the armed services did rate all audible signals in decibels and made a specific distance from the microphone a part of their specification. The Army Air Forces used three feet; the Navy 18 feet and 15 feet. Some Signal Corps specifications called for a definite sound-pressure output expressed in dynes per square centimeter.

Prize winners at Seattle Section AIEE meeting

Front row, left to right: K. L. Schubert, C. F. Myers, R. A. Walker, Alvia Lohaff (guest), J. W. Ferguson, C. C. Cornfield, J. A. Schrengohst, J. W. Allen, and T. B. Correy. Rear row, left to right: L. A. Traub, C. D. Howe, R. E. Kistler, A. H. Kassens, H. R. Brown (secretary-treasurer), C. H. Cutter (chairman), G. H. Walker, E. B. Hansen (vice-chairman) and Art Kramer

By and large, Mr. Ruth claimed, the services were ahead of the audible-signal industry.

Before the influx of large orders from the armed services the industry in general rated gongs by the diameter of the gong shell. Navy specifications would not generally accept the no-contact types—an improvement over the contact, clapper types in their long life and nonradio-interference characteristics—contending that the 60-beat action was entirely too fast for efficient sound output of the gong shell. Many bells for Navy use were for operation on 60-cycle alternating current, but in some instances only direct current was available for signaling. Therefore, a-c and d-c audible signals were required. The Signal Corps required d-c signals only. The Army Air Forces use 30-volt d-c generators for signaling and d-c signals are the rule in this branch of the service. In general, specifications of the armed services uniformly called for audible signals to withstand, without impairing their efficiency, the effects of vibration, salt spray, and moist humid atmospheres encountered in the tropics, and the effect of extremely low temperatures.

Mr. Ruth concluded his talk with some interesting data on the use of aluminum for the cases and covers until the aluminum shortage and the subsequent shortage of copper products called for the ingenuity of all in the use of steel as a solution.

High-Frequency Heating Developments Reviewed

Some of the accomplishments of industry at war through the electronic development of high-frequency heating and the possibilities for its applications in peacetime were related by Carl J. Madsen (M '44) electronics engineer of the Westinghouse Electric Corporation, East Pittsburgh, Pa., at a recent meeting of the Charleston, W. Va., Section of the AIEE. He said that proper industrial application of dielectric heating can increase production two to ten times that obtained by other methods, and that it also can decrease the number of rejects of a manufactured item, and result in an improved final product.

In the inductive field, applying high frequencies to objects that are conductors, great strides also have been made, the speaker said. Inductive applications are now widely used in the case-hardening of gear teeth and bearings, in brazing, soldering, and heat-treating. Heat-treating by induction often saves as much as 20 per cent of time and cost in manufacturing process, Mr. Madsen said, because it left no scale to be removed as do older methods of heat-treating. Electrolytically deposited tin is being "flowed" in a continuous process line at speeds of more than 1,000 feet per minute. This process produces mirror-smooth tin plate suitable for many purposes.

Mr. Madsen remarked further that electronic tubes create the waves that case-harden engine parts. The electrical current produced by these tubes and sent into an induction coil to be transferred into the engine part may change its direction of flow as often as 900,000 times a second. By varying this frequency and time, the depth of the hard-metal coating can be controlled to within a few hundredths of an inch.

Section Works for City Betterment. The public relations committee of the AIEE Houston Section has prepared and presented a completely rewritten electrical code for adoption as a part of the new city building code. This work was done at the request of the officials of Houston, Tex.

STANDARDS . . . .

Recommended Practice for Electrical Installations on Shipboard. The AIEE committee on marine transportation has prepared a revision of AIEE Standard 45, "Recommended Practice for Electrical Installations on Shipboard." This revision was approved by the Standards committee on June 25 and by the board of directors on June 27. The revision is now in the hands of an editing committee. When its work is completed, the publication of the revision will then get under way. The new edition, which will supersede the present issue of 1940, will not be available until the end of 1945.

Code for Protection Against Lightning. The National Bureau of Standards has issued a revision of the Code for Protection Against Lightning, Parts I, II, and III. This is known as Handbook *H*40 (superseding *H*21) and is available through the Superintendent of Documents, Washington, D. C., at a cost of 20 cents. This revision was prepared by a sectional committee working under the rules of procedure of the American Standards Association and the sponsorship of the Institute, the National Bureau of Standards, and the National Fire Protection Association. Parts I and II remain as in the previous edition; only part III has been revised.

Expulsion-Type Distribution Lightning Arresters. A subcommittee of the AIEE committee on protective devices has prepared a proposed standard on "Expulsion-Type Distribution Lightning Arresters." This was approved by the Standards committee on June 25 and by the board of directors on June 27 for publication by the Institute as a "Proposed Standard." Notice of availability will be given in these columns.

Sign of Reactive Power. A special subcommittee of the Standards committee, under the chairmanship of R. C. Bergvall, has been at work for more than a year studying the question of the sign for reactive power. This controversial subject was first considered by a special committee of the Standards committee in 1933. Following the acceptance of that committee's report by the AIEE Standards committee, recommending a negative sign (the vector for reactive power to be drawn downward), the convention became an American Standard and later was approved by the International Electrotechnical Commission. The convention of the negative sign was adopted by the commission in 1936. In 1944, the Institute's committee on power transmission and distribution asked for a reopening of the question, pointing out that the existing standard was actually in conflict with the generally accepted practice of the operators. The Standards committee therefore again referred the matter to a new subcommittee with instructions that a careful review of all phases of the problem be undertaken. A comprehensive canvass was made and the committee's report recommending a reversal of the present Standard from a negative sign to a positive sign was received by the Standards committee at the meeting on June 25, at which time (following a protest on the reversal of the present Standard by the AIEE instruments and measurements committee) the report was ordered referred to the American Standards Association for consideration.

Conduction in Stationary Contact Surfaces. A revised report of the subcommittee, W. P. Dobson, chairman, on conduction in stationary contact surfaces, of the Standards committee will shortly be available in mimeographed form. Those interested may obtain copies from Institute headquarters.

Turbine-Generator Standards and Specifications. A new pamphlet in the AIEE Standards series is now available covering "Preferred Standards for Large 3,600-Rpm Three-Phase 60-Cycle Condensing-Type Steam-Turbine Generators" and "Standard Specification Data for Generators," for such units, both in the class of machines larger than 10,000-kw capacity. A detailed account of these Standards for steam turbine generators was given in *Electrical Engineering*, May 1945, page 180. These publications are identified as 601 and 602 in the AIEE series and are published as one pamphlet at a cost of 30 cents, with the usual 50-per-cent discount to AIEE members on single copies.

Electric Welding Standards Withdrawn. The two former AIEE Standards 38 and 39, "Electric Arc Welding Apparatus" and "Resistance Welding Apparatus" (American Standards Association *C*52.1 and *C*52.2) respectively, approved and published in 1933 were withdrawn at the suggestion of the Institute by official action of the ASA on April 13, 1945. This action was necessary as the two Standards were considered obsolete. The work of preparing revised standards is going forward under the control of a sectional committee sponsored by the American Welding Society.

Test Code for Synchronous Machines. A revised edition of "AIEE Test Code for Synchronous Machines," originally issued in 1937 as a report on a proposed code, was approved by the Standards committee on June 25 and by the board of directors on June 27. The preparation of this revised code was carried out by a subcommittee of the committee on electric machinery, L. A. Kilgore, chairman. This code contains in-

structions for conducting the more generally applicable and accepted tests to determine the performance characteristics of synchronous machines. It is not intended that the code shall cover all possible tests, or tests of a research nature. It includes performance tests for synchronous generators and motors (larger than fractional horsepower) synchronous condensers, frequency changers, and rotary phase advancers. Copies may be obtained from AIEE headquarters, 33 West 39th Street, New York 18, N. Y., at a cost of 60 cents each, with the usual 50-percent discount to members on single copies.

Third Progress Report on AIEE Aeronautical Standards

Many members of the Institute are participating in the standardization work on aeronautical equipment, the scope of which was outlined previously in progress reports of October 1944 and February 1945 (*EE, Nov '44, p 412, March '45, p 122*). Cooperation is being given by other interested organizations. J. D. Miner, Jr. (M '42) engineering manager, small motor division, Westinghouse Electric Corporation, Lima, Ohio, has been appointed chairman of this committee, succeeding D. R. Shoults (M '42). The work being carried on by the four active subcommittees is summarized as follows:

AIRCRAFT ELECTRIC SYSTEMS SUBCOMMITTEE

Under the chairmanship of R. H. Kaufmann (M '41) a memorandum outlining the scope and subject material proposed for the informative type of report was prepared and widely distributed throughout the industry to competent engineers and aeronautical authorities, inviting contributions of pertinent data. Aeronautical Radio, Inc., is fully co-operating in this work along with the Society of Automotive Engineers, National Electrical Manufacturers Association, the Army Air Forces, and the Navy Bureau of Aeronautics. A. F. Trumbull (M '44) aeronautical engineer, recently was appointed a member of this subcommittee. Individual topic assignments have been given and it is expected that a first draft of the proposed report will be prepared shortly. Substantial progress has been made on the formulation of procedures for evaluating the volt-ampere characteristics of composite aircraft systems.

AIRCRAFT ELECTRIC ROTATING MACHINERY SUBCOMMITTEE

This group under the chairmanship of M. L. Schmidt (M '43) is engaged in preparing a test code for aircraft electric machinery, the scope of which will be "all rotating machinery which operates from/or is connected to a d-c system of an airplane." A first draft of this code has already been outlined and is now in the process of preparation.

AIRCRAFT ELECTRIC CONTROL AND PROTECTIVE DEVICES SUBCOMMITTEE

This group under the chairmanship of R. A. Millermaster (M '34) has as its responsibility the preparation of standards and test codes. It is collaborating with the Electrical Systems Subcommittee in developing a more adequate procedure for testing the interrupting capacity of aircraft circuit breakers.

AIRCRAFT WIRE AND CABLE SUBCOMMITTEE

This group under the chairmanship of W. S. Hay is preparing a test code for evaluating aircraft wire and cables and recommendations for the protection of aircraft wire and cable circuits, considering short-time and long-time thermal abilities and environmental conditions, and reviewing the present methods of rating aircraft wires and cables. Considerable progress has been made in standardizing methods of testing and evaluating aircraft cable thermal test data.

AIRCRAFT D-C APPARATUS VOLTAGE RATINGS

A report is now available as AIEE publication 700 and is being given wide distribution throughout the industry.

SAE AIRCRAFT ACCESSORIES AND EQUIPMENT

The Institute was represented at a meeting of Society Automotive Engineers committee *A-2*, aircraft electric equipment, at Dayton, Ohio, on May 29–30, with C. C. Shangraw, chairman, presiding. Discussion was held on *AN-M*-10 aircraft, d-c 24-volt motors, *A-N* aeronautical specification, thermal protection for electric motors, industry standardization of aircraft electric equipment, cooling-air requirements for generators, alternators and motors, spline lubrication, and standardization of ground to aircraft servicing equipment connections.

PERSONAL • • • • •

T. S. Oliver (A '30, M '43) underground engineer, Public Service Company of Colorado, Denver, **N. R. Love** (A '25, M '38) chief engineer, Denver Tramway Corporation, and **Hubert Sharp** (A '25, M '31) protection engineer, Mountain States Telephone and Telegraph Company, Denver, have been awarded the 1944 District 6 best paper prize for their paper, "The Effect of Large Rectifiers on Power-System Wave Shape and Telephone-Circuit Noise." Mr. Oliver was born in Chester, Pa., and was graduated from Swarthmore College in 1925. He was associated with the Westinghouse Electric and Manufacturing Company, on the test floor as regular tester, and with the Philadelphia Electric Company as technical assistant. Mr. Love was born in London, England, in 1892 and was graduated from the Colorado College with the degree of bachelor of science and as electrical engineer. From 1912–15 he worked as a special apprentice with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., specializing in works management. From 1915–17 he served as instructor in electrical engineering at Colorado College, Colorado Springs. In the latter year he became associated with the Denver Tramway Company and served as special study engineer, assistant chief engineer, and chief engineer. Mr. Sharp was born in Blackwater, Ariz., and was graduated with the degree of bachelor of science in electrical engineering from the University of California. He has been associated with the Mountain States Telephone and Telegraph Company since 1917, first doing drafting and and surveying work, then equipment installation and circuit work, and later serving as electrical engineer's assistant, and protection engineer's assistant.

P. S. Clapp (A '18) vice-president of the Columbia Gas and Electric Corporation, Columbus, Ohio, who has recently been awarded the Marston Medal, was born at Toledo, Iowa. He was graduated from Iowa State College in 1913 as an honor student in electrical engineering. His engineering career started with a student-training course at the Western Electric Company in Chicago, Ill. Later he transferred to the New York laboratories where he assisted with the work being done on the then newly developed vacuum tube. In 1917 he became assistant purchasing agent for the Allied Machinery Company. With the entry of the United States into World War I, he became a captain in the Signal Corps and was in charge of engineering of communications for tanks and airplanes at the laboratories in Little Silver, N. J. In France in 1918 he established a factory for the final assembly of small dry-cell batteries for the American Expeditionary Forces. With the end of the war, he was assigned to the Allied Peace Commission, and also served on the Allied Relief Commission under Herbert Hoover. He then returned to the Western Electric Company, but was invited to travel to Russia in 1921 as a member of the Russian Food Relief Commission. In 1923 he was personal assistant to Herbert Hoover and three years later was made managing director of the National Electric Light Association. In 1932 he was named vice-president of the Columbia Gas and Electric Corporation and since that time has been associated with that organization and its subsidiaries.

H. T. Kohlhaas (M '19) editor of *Electrical Communication*, technical journal of the International Telephone and Telegraph Corporation, New York, N. Y., has been appointed an assistant vice-president. Mr. Kohlhaas received the bachelor-of-science degree in general science from Cooper Union in 1907, three years later he was awarded the degree of electrical engineer from the Brooklyn Polytechnic Institute, and in 1914 was awarded the same degree from Cooper Union. In 1905 he became associated with the Western Electric Company taking a special students' training course and acting as telephone and telegraph inspector In 1908 he was engaged in engineering check inspection of telephone and telegraph apparatus. For the next six years he was engaged in designing telephone apparatus and subsequently was in charge of the apparatus

analysis section in the physical laboratory. In 1922 he was appointed executive personnel assistant to the system's engineer of Bell Telephone Laboratories, Inc., and later Mr. Kohlhaas was transferred to the International Western Electric Company to make statistical studies and to serve as editor of *Electrical Communication*. Through the purchase of that company he became a member of the staff of the International Telephone and Telegraph Corporation. During 1937–39 he edited the journal from London serving also as publicity representative of the International Telephone and Telegraph Corporation and the International Standard Electric Corporation.

William Spraragen (A '17, M '26) executive secretary of the Welding Research Council, New York, N. Y., has been appointed to the newly created position of director. Mr. Spraragen was born in Warwick, N. Y., and was graduated from Union College with a bachelor-of-engineering degree in 1916. His career includes service with the General Electric Company in charge of the test department, with the testing department of the Westinghouse Electric Corporation; and as instructor of electrical engineering at the University of Washington, Seattle. Mr. Spraragen has long been identified with research and welding. He has served as executive secretary of the Welding Research Council since its organization in 1935 and his connection with the welding industry dates back to 1918 when he was appointed research assistant to the Welding Research Committee of the National Council of Defense and the Emergency Fleet Corporation. From 1920–34 Mr. Spraragen was secretary of the division of engineering, National Research Council and secretary of the American Bureau of Welding from 1921–36. He served as technical secretary of the American Welding Society from 1927–42. He is editor and business manager of *The Welding Journal*, official publication of the society of which he has been editor since publication was started in 1922. He is author or coauthor of many critical reviews of the literature on practically every phase of welding. He was a member of the AIEE electric welding committee for several years.

C. R. Burrows (A '26, M '33) of the radio research engineering department of the Bell Telephone Laboratories, Inc., New York, N. Y., has been appointed professor of electrical engineering and director of the school of electrical engineering at Cornell University, Ithaca, N. Y. He will assume his new duties in September. Doctor Burrows was born in Detroit, Mich., and received the degrees of bachelor of science in engineering, and electrical engineering from the University of Michigan and the degrees of master of arts and doctor of philosophy from Columbia University. He began his engineering career with the Western Electric Company, New York, N. Y., which became identified with Bell Telephone Laboratories, Inc., in 1925. For three years he was engaged in transatlantic and South American transmission experiments on the development of short-wave radiotelephone channels. He spent one year on experimental and theoretical study of phase modulation and the distortion it introduces in the received signal; two years on tuned antennas; seven years as supervisor of a group of engineers making an experimental investigation of the propagation characteristics of ultrashort waves; one year on the exponential transmission line; and since 1938 he has been engaged in research on ultrashort-wave transmitters. Doctor Burrows is the author of a number of papers dealing with these investigations.

B. V. Hoard (M '36) chief, a-c calculating board studies unit, Bonneville Power Administration, Portland, Oreg., and **G. W. Bills** (A '38) United States Naval Reserve, have been awarded the 1944 District 9 best paper prize for their paper, "An Analysis to Determine the Optimum Bussing Arrangements and Transmission Capabilities at Grand Coulee." Mr. Hoard was born in Elk City, Okla., and was graduated from the University of Washington in 1924 with the degree of bachelor of science in electrical engineering. From 1925–26 he was an engineering student with the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and from the latter year to 1931 he served as electrical engineer in the general engineering department. For the next two years Mr. Hoard taught electrical engineering at the University of Pittsburgh, Pa. In 1933 he went with the Consolidated Edison Company of New York, Inc., New York, and was employed as junior engineer and later engineering assistant. Mr. Bills was born in Tacoma, Wash., and was graduated in June 1938 as electrical engineer from the University of Washington. He became a teaching fellow at the University of Washing, Seattle, and in 1939 was made junior electrical engineer, Bonneville Dam project, Portland, Oreg.

R. D. McManigal (A '18) manager, associated companies department, Westinghouse Electric International Company, New York, N. Y., has been elected a vice-president of that company. After his graduation with the degree of electrical engineering from Lafayette College, Mr. McManigal joined the Westinghouse Company in 1915. He completed the company's student course, and for seven years, except for a period of service in the United States Navy during World War I, he was in the general engineering division at East Pittsburgh, Pa. In 1922 he went to Japan as an engineer for the Westinghouse Electric International Company and later served as managing director of the Westinghouse Electric Company of Japan. In 1931 upon the dissolution of that company he returned to New York and has served in the capacity of manager of the central station-transportation apparatus department, assistant to the vice-president, and manager of the associated companies department, his most recent post.

E. A. Walker (A '34, M '41) who has been in charge of the Ordnance Research Division at Harvard University, Cambridge, Mass., will be the director of the Ordnance Research Laboratory, dealing with underwater ordnance, at the Pennsylvania State College, State College, Pa., and the head of the electrical engineering department of the college. Doctor Walker was born in Long Eaton, England, and is a graduate of the Harvard Engineering School having received the degrees of bachelor of science in 1932 and master of science in 1933. He has been assistant professor of electrical engineering at Tufts College, Tufts College, Mass., and also head of the electrical engineering department at the University of Connecticut, Storrs. He has been associated with the Doble Engineering Company and the Colt Patent Fire Arms Company as a consultant. His research projects include work on the behavior of dielectrics at high voltages, the effect of moisture and aging on insulating oils, and the development of weapons for the Bureau of Ordnance.

William Fondiller (M '15, F '26) assistant vice-president of the Bell Telephone Laboratories, Inc., New York, N.Y., was awarded the university medal by Columbia University at the commencement exercises on June 5, 1945. Mr. Fondiller was born in Minsk, Russia, and was graduated from the College of the City of New York with the degree of bachelor of science in 1903, from Columbia University with the degree of electrical engineer in 1909, and received his master-of-arts degree from the same university in 1913. He began his practice of electrical engineering in the physical laboratory division, engineering department of the Western Electric Company, New York, N. Y. By 1920 he was in charge of a group of 75 engineers engaged in the commercial development of all wound apparatus used in the Bell system. In 1923 he became head of the general development laboratory comprising a staff of 190 people. Mr. Fondiller served as a member of the AIEE electrophysics committee from 1922–24 and is the author of numerous papers.

Dimiter Ramadanoff (M '37) research electrical engineer and physicist of the National Carbon Company, New York, N. Y., has been awarded the 1944 best paper prize for his paper, "High-Altitude Brush Problem." Mr. Ramadanoff was born in Sofia, Bulgaria, and received the bachelor-of-science degree in electrical engineering from the University of Illinois in 1924, and the doctor-of-philosophy degree from Cornell University in 1932. In the summers of 1920–1923 he worked with the American Steel Foundries in Granite City, Ill., and as electrician with the Chicago and Northwestern Railway in Chicago, Ill. Successively thereafter he was research physicist at the University of Illinois, installation engineer, Ward Electric Company, Miami Beach, Fla., electrical engineer, Michigan Bell Telephone Company of Detroit; instructor in electrical engineering at Cornell University, Ithaca, and research engineer with the research laboratory of the General Electric Company.

C. K. Duff (A '28, M '41) meter engineer, operating department, Hydro-Electric Power Commission of Ontario, Toronto, Canada, was awarded the 1944 District 10 best paper prize for his paper, "Load, Frequency, and Time Control of Interconnected Systems." Mr. Duff was born in Hamilton, Ontario, Canada, and was graduated from the University of Toronto with the degree of bachelor of applied science in electrical engineering in 1918. From 1918–21 he was research assist-

ant, school of engineering research, faculty of applied science University of Toronto. From 1921–27 he was a teacher of science in Wesley College, Wuchang, Hupeh, China, and in the last-mentioned year he again was research assistant, school of engineering research, University of Toronto, doing researches on automatic speed and frequency control. In 1934 he took the position of meter engineer with the Hydro-Electric Power Commission.

C. C. Crane (A '25, M '31) chief engineer of the Wisconsin Electric Cooperative, Madison, has resigned to enter the consulting engineering field in Madison. Mr. Crane was born in Hillsdale, Mich., and was graduated from the University of Michigan in 1923 with the degree of bachelor of science in electrical engineering. He has spent most of his time in the design and construction fields with various public utilities, among them the Utah Power and Light Company, Salt Lake City, and the Commonwealth Power Corporation, Jackson, Mich. In 1938 he joined the staff of the Federal Power Commission, Washington, D. C., and in 1942 was assigned to the inventory control branch of the Office of War Utilities. In October 1943 he returned to the power section of the Federal Power Commission.

J. T. Madill (A '41) system protection engineer, Aluminum Power Company, Ltd., Shipshaw, Quebec, Canada, was awarded the 1944 District 10 initial paper prize for his paper, "Field Decay Characteristics of Large Hydroelectric Generators." Mr. Madill was born in Edmonton, Alberta, Canada, and was graduated from the University of Alberta with the degree of bachelor of science in electrical engineering in 1939, and received a master-of-science degree in 1940 from Massachusetts Institute of Technology. Before his affiliation with the Aluminum Power Company he was employed in the design and appraisal division of the Ebasco Services, Inc., New York, N. Y., where he assisted in preparing systems for study on the a-c network analyzer.

C. G. Mansfield (A '25, M '42) assistant underground design engineer, design and construction division, water and power department, City of Los Angeles, Calif., has been awarded the 1944 District 8 initial paper prize for his paper, "New 138-Kv Cable Lines in Los Angeles." Mr. Mansfield was born in Danbury, Conn., and received the bachelor-of-science degree in electrical engineering in 1923 from the University of Wisconsin. He joined the General Electric Company, Schenectady, N. Y., as student in the test course, later becoming engineer at the Pittsfield, Mass., office. In 1926 he became affiliated with the Los Angeles Bureau of Power and Light and has conducted numerous investigations and studies relating to that system.

Alfred Glasgow (A '08) formerly assistant superintendent of transmission and distribution, San Diego (Calif.) Gas and Electric Company, has been made department superintendent. Mr. Glasgow, a 1901 graduate of Pennsylvania State College, entered the employ of the San Diego company in 1916 as manager of its Oceanside district. He previously had been associated with the General Electric Company, Schenectady, N. Y.

E. E. Scofield (A '43) of the consulting and research department, Washington Water Power Company, Spokane, has been made manager of wholesale and special contracts. Mr. Scofield, who has been with the company since 1922, has been draftsman, assistant industrial engineer, manager of industrial sales, assistant manager of the rate department, and supervisor of power contracts and statistics.

S. G. Hibben (A '34) director of applied lighting and **C. M. Slack** (M '43) assistant director of research, lamp division, Westinghouse Electric and Manufacturing Company, Bloomfield, N. J., have been awarded the Westinghouse order of merit. Mr. Hibben was honored for his development work on light. Doctor Slack was cited for creating high-speed X-ray tubes and developing their wartime applications.

W. D. Kleppinger, Sr. (A '39) formerly assistant engineer with Consolidated Edison Company of New York (N. Y.), Inc., and later general superintendent for Ford, Bacon and Davis, Inc., New York, has accepted a commission as lieutenant (junior-grade), United States Naval Reserve, and has been assigned temporarily to the industrial department of the Philadelphia (Pa.) Navy Yard.

R. B. Hubbard (A '20, M '28) director of the industrial development department, Public Service Company of Colorado, Denver, and newly elected president of the Colorado Engineering Society, has been made manager of the Rocky Mountain Electrical League. Mr. Hubbard has been granted a two-year leave of absence by the Public Service Company.

C. H. Spiehler (M '28) mechanical engineer, Cincinnati (Ohio) Gas and Electric Company, has accepted the position of mechanical consulting engineer for the Dayton (Ohio) Power and Light Company. Mr. Spiehler rejoins the company, after having been with them from 1910 until 1926 in the design and operation of the district heating and power stations.

E. W. Baker (A '40, M '44) formerly head of the toll transmission group, American Telephone and Telegraph Company, New York, N. Y., has been appointed head of a recently organized group on toll-line dialing and new special services. Mr. Baker, a 1924 graduate of Lehigh University, has been employed by the Bell System since his graduation.

H. I. Romnes (A '41) operation engineer, engineering department, American Telephone and Telegraph Company, New York, N. Y., has been appointed head of the company's toll transmission group. Mr. Romnes, who formerly was employed by Bell Telephone Laboratories, Inc., New York, has been in the transmission section since 1935.

H. R. Lee (A '38, M '44) of the electric transmission-line department, United States Bureau of Reclamation, Denver, Colo., has been named power manager. Mr. Lee is a former chief of the power marketing and sales division of the bureau and for a time was Denver regional utility engineer for the War Production Board.

A. W. Milliken (A '30) vice-president, New York State Electric and Gas Corporation, Brewster, has been made superintendent of operations. Mr. Milliken, who has been a vice-president and manager of the company's eastern division since 1939, was associated with the New Bedford (Mass.) Gas and Edison Light Company from 1922 to 1939.

N. L. Rea (A '02) superintendent of electrical installations, contract service department, General Electric Company, Schenectady, N. Y., has been made engineering consultant in the service engineering division of the company. **W. C. Plumer** (A '24, M '30) engineer, General Electric Company, Buffalo, N. Y., succeeds Mr. Rea.

C. W. McGill (A '35, M'44) formerly head of the transmission and station planning division, Boston (Mass.) Edison Company, has become head of the company's electrical section. **E. A. Church** (A '29, M'45) of the company's engineering department succeeds Mr. McGill.

J. J. Smith (A '19) assistant engineer, general engineering laboratory, General Electric Company, Schenectady, N. Y., has been appointed chairman of the American Standards Association war committee on methods of measuring radio noise.

L. S. Curs (A '38) lieutenant colonel, Signal Corps, United States Army, has been awarded the Bronze Star medal. He was cited for his services in the installation of radio, telephone, and teletype facilities in the Persian Gulf Command.

Harold Goldberg (A '35, M'44) formerly senior engineer with the Stromberg-Carlson Telephone Manufacturing Company, Rochester, N. Y., has been appointed a research engineer of the radio division, Bendix Aviation Corporation, Baltimore, Md.

P. L. Bellaschi (A '29, F '40) development engineer, Westinghouse Electric and Manufacturing Company, Sharon, Pa., has returned from a four-months' tour of South America for the Westinghouse International Company.

S. B. Storer (A '39) managing engineer, Norwood (Ohio) division, Trumbull Electric Manufacturing Company, has been appointed to the panelboard and distribution-board section of the National Electrical Manufacturers Association.

S. V. Hart (A '43) now application and development engineer, Radio Corporation of America, Indianapolis, Ind., was incorrectly referred to as **S. B. Hart** in the notice of his appointment which appeared in the March 1945 issue of *Electrical Engineering*.

E. P. Fetherstonhaugh (A '09) professor of electrical engineering and dean of the faculty of engineering and architecture, University of Manitoba, Winnipeg, Canada, has been elected president of the Engineering Institute of Canada.

H. L. Etheridge (M '44) formerly chief of engineering section, Newfoundland Base Command, United States Army, is now in the engineering division, Raytheon Manufacturing Company, Waltham, Mass.

J. L. Woodress (A '07, M '21) assistant secretary and director of sales, Century Electric Company, St. Louis, Mo., has been elected president of the St. Louis Electrical Board of Trade.

J. F. Peters (M '14 F '23) consulting engineer, Westinghouse Electric Corporation, East Pittsburgh, Pa., has been awarded the order of merit, highest honor bestowed on an employee.

E. P. Bancroft (M '42) general department, International Standard Electric Company, New York, N. Y., is in Rio de Janeiro, Brazil, in order to study the communications situation in that country.

F. R. Lack (M '37) vice-president and manager, radio division, Western Electric Company, Inc., New York, N. Y., has been elected to the board of directors of the American Standards Association.

P. G. Weiller (A '43) formerly in charge of the research department, Square D Company, Woodside, N. Y., has established offices and a research laboratory in New York, N. Y.

O. W. Titus (A '29, F '44) chief engineer of the Canada Wire and Cable Company, Ltd., Toronto, Ontario, Canada, has been elected president of the Toronto Electric Club.

M. J. Kelly (M '26, F '31) executive vice-president of the Bell Telephone Laboratories, Inc., New York, N. Y., has been elected a member of the National Academy of Science.

OBITUARY • • • • •

C. W. Caldwell (A '32) associate professor of electrical engineering, Purdue University, Lafayette, Ind., died on June 5, 1945. He was born in Warren, Ind., and received the degree of bachelor of science in electrical engineering in 1931, and the master-of-science degree in engineering in 1938 both from Purdue University. After teaching school in the rural districts of Huntington County and serving as electrician in Marion, Ind., he became assistant instructor in the drawing department of Purdue University serving in that capacity from 1927–29. Subsequently, he was research assistant in the electrical-engineering experimental station of that university from 1929–31. In 1931 he became acting head of the school of electrical engineering, University of South Dakota, Vermillion, and two years later was made head of the physics department where he remained until 1934. In the last-mentioned year he became instructor in electrical engineering at Purdue University, later becoming assistant professor and in charge of the electronics course.

C. F. Hanson ((A '18, M '37) chief consulting engineer, sales department, Irvington Varnish and Insulator Company, Irvington, N. J., died on April 27, 1945. Mr. Hanson was born in Arkansas City, Kan., and received the bachelor-of-science degree in electrical engineering and the degree of master of science from the University of Kansas in 1912 and 1913 respectively. From 1913–18 he served as assistant physicist with the Bureau of Standards, Washington, D. C., and from 1918–27 he was research director of the Habirshaw Cable and Wire Corporation, Yonkers, N. Y. For the next three years he was engaged in oil research for the R. T. Vanderbilt Company, East Norwalk, Conn. In 1930 he became affiliated with the Irvington Varnish and Insulator Company as technical director. He served on the AIEE instruments and measurements committee 1926–27. He was the author of "Required Power Factor Accuracy of Paper Cables."

H. R. Palmer (A '08, M '21) head electrical engineer, bureau of engineering, electrical section, Pennsylvania Public Utilities Commission, Harrisburg, died recently. Mr. Palmer was born in Murray, Orleans County, N. Y., in 1868. Early in his career he was identified with the Morristown Light, Heat and Power Company, Morristown, N. J., the Virginia Railway and Power Company operating electric light and power, and street railway in Richmond, Petersburg, Suffolk, and Norfolk, and later served as vice-president and general manager of the Harrisburg Light and Power Company, Harrisburg, Pa. For the last-mentioned he had direct general supervision of construction and operation of electric and steam heat systems, including steam and generating stations.

J. H. Bonine (A '17) partner in the Bra Bon Electric Company, Philadelphia, Pa., died May 12, 1945. He was born in Lancaster, Pa. In 1914 he became affiliated as construction engineer with the firm of Lewis and Roth Company which designed and built substations for plants making new materials, such as the Baldwin Locomotive Works, and Standard Steel Works. Later he became superintendent of the switchboard department of Lewis and Roth. Following the war's end he became secretary of the Electric Power Equipment Corporation of Philadelphia, successor to Lewis and Roth. In 1930 with C. S. Brangan he formed the Bra Bon Electric Company as manufacturers' agents.

C. R. Horrell (A '16, M '25), vice-president and general sales manager of the Sangamo Electric Company, Springfield, Ill., died on July 5, 1945. He was born in Stockville, Neb., on December 15, 1889, and was graduated from the University of Illinois with a bachelor-of-science degree in electrical engineering in 1913. He was first associated with the engineering sales department of the Electric Appliance Company, Chicago, Ill., where his work consisted chiefly of designing and laying out distribution and necessary connecting transmission lines. In 1919 he became sales manager of the Sangamo Electric Company and was appointed vice-president in 1941.

E. P. Karr (A '40) field engineer, Public Service Commission of Kentucky, Lexington, and a major in the United States Army was killed in action in Belgium on January 6, 1945. Major Karr was born in Lexington, Ky., in 1917, and received his bachelor-of-science degree in electrical engineering from the University of Kentucky in 1938 and the master-of-science degree from the same university the following year. He entered the service in June 1941 and had been overseas with the Signal Corps since October 1943.

A. J. Clarkson (M '26, F '34) superintendent of electric equipment, New York Central System, New York, N. Y., died on June 4, 1945. Mr. Clarkson was born on August 4, 1893, at Bloomington, Ill., and was graduated from the engineering department of the University of Illinois with the degree of bachelor of science. In 1916 he became associated with the New York Central System as draftsman and served in turn as checker, senior draftsman, inspector, and general inspector.

Adolph Hertz (A '18) statistician with the New York Edison Company, New York, N. Y., when he retired in 1933, died on May 31, 1945. Though born in Germany in 1867, and educated in England, Mr. Hertz became a citizen of the United States. He designed many of the electric rates used by the Edison company and by other utilities in the United States.

MEMBERSHIP • • •

Recommended for Transfer

The board of examiners, at its meeting of July 19, 1945, recommended the following members for transfer to the grade of membership indicated. Any objections to these transfers should be filed at once with the secretary of the Institute.

To Grade of Fellow

Gray, T. S., associate professor, Mass. Inst. of Tech., Cambridge, Mass.

Grigsby, L. C., elec. engr., Public Service Co. of Okla., Tulsa, Okla.

Groves, W. M., Jr., plant extension engr., Southwestern Bell Tel. Co., Dallas, Tex.

Lafferon, C. M., mgr., A. C. Engg. Dept., Westinghouse, Elec. Corp., E. Pittsburgh, Pa.

McFarland, T. C., chairman, div. of elec. engg., Univ. of California, Berkeley, Calif.

Miller, L. E., engr. in chge. of quality, Reliance Elec. & Engg. Co., Cleveland, Ohio.

Nott, G. E., chief engr., Pacific Tel. & Tel. Co., Seattle, Wash.

Robertson, L. M., trans. & station engr., Public Service Co. of Colorado, Denver, Colo.

Shute, E. R., vice-pres., Western Union Tel. Co., New York, N. Y.

Todd, J. M., cons. engr., Maritime Bldg., New Orleans, La.

Westbye, J. B., elec. engr., Gibbs & Hill, Inc., New York, N. Y.

Whitehead, E. R., investigating engr., Duquesne Light Co., Pittsburgh, Pa.

12 to grade of Fellow

To Grade of Member

Abfalter, E. J., asst. sec. engr., Fisher Body Div., General Motors Corp., Detroit, Mich.

Angel, H. H., asst. to elec. supt., Bethlehem Steel Co., Sparrows Point, Md.

Baccus, I. B., U. S. Navy, instructor in elec. engg., U. S. Naval Academy, Annapolis, Md.

Bodine, R. B., engr., General Elec. Co., Schenectady, N. Y.

Buchanan, D. V., asst. engr., Cons. Edison Co. of N. Y., Inc., New York, N. Y.

Christensen, P. L., chief, fuse & special device sec., Office, Chief of Ordnance, Washington, D. C.
Ellworth, B. E. S., elec. engr., Nebraska Public Power System, N. Platte, Neb.
Fager, C. R., elec. engr., Mare Island Navy Yard, Mare Island, Calif.
Fagerlund, A. C., elec. engr., Air Technical Service Command, Wright Field, Dayton, Ohio.
Flora, W. W., private practicing & cons. engr., Flora Engineering Co., Cheyenne, Wyo.
Friedman, A., vice-pres. in chge. of engg., Columbia Elec. Mfg. Co., Cleveland, Ohio.
Garr, D. E., engg., General Elec. Co., Schenectady, N. Y.
Gise, L., district engr., Westinghouse Elec. Corp., Philadelphia, Pa.
Gorman, W. J., Jr., elec. engr., General Elec. Co., Schenectady, N. Y.
Gottron, G. L., member of technical staff, Bell Tel. Labs., Inc., New York, N. Y.
Grigsby, J. M., elec. engr., Modesto Irrigation District, Modesto, Calif.
Hammond, J. W., Comdr., USNR, Philadelphia Navy Yard, Philadelphia, Pa.
Harmer, R. G., dist. engr., Westinghouse Elec. Corp., Philadelphia, Pa.
Heidelberger, O., elec. design engr., Master Elec. Co., Dayton, Ohio.
Hokanson, H. T., application engr., General Elec. Co., Schenectady, N. Y.
Hyde, M. A., Jr., elec. engr., Westinghouse Elec. Corp., East Pittsburgh, Pa.
Johnson, R. F., design engr., General Elec. Co., Fort Wayne, Ind.
Jones, O. N., president, Ambos-Jones Co., Cleveland, Ohio.
Kres, A. J., engr., Ohio Bell Tel. Co., Cleveland, Ohio.
Kron, G., cons. engr., General Elec. Co., Schenectady, N. Y.
Larrick, C. V., Jr., elec. engr., General Elec. Co., Schenectady, N. Y.
Lee, C. F., engr., General Elec. Co., Cincinnati, Ohio.
Lord, H. W., engr., General Elec. Co., Schenectady, N. Y.
Manring, R. C., project engr., Combined Research Group, Naval Research Lab., Washington, D. C.
Martin, C. A., chief engr., Dingle-Clark Co., Cleveland, Ohio.
Mendelsohn, L. I., development engr., General Elec. Co., Lynn, Mass.
Menes, F. A., Jr., chief engr., Line Equip. Sect., Signal Corps Ground Signal Agency, Red Bank, N. J.
Miller, G. E., industrial engg. div., General Elec. Co., Schenectady, N. Y.
Miller, F. L., requisition engg., General Elec. Co., Schenectady, N. Y.
Morris, J. A., meter engr., American Gas & Elec. Serv. Corp., New York, N. Y.
Morris, J. A., meter engr., American Gas & Elec. Serv. Corp., New York, N. Y.
Muir, W., ind. control engg. div., General Elec. Co., Schenectady, N. Y.
Nelson, E. P., consultant, 29 Crest St., New London, Conn.
Oewel, J. A. G., engr., Pennsylvania Power & Light Co., Allentown, Pa.
Palka, G. A., elec. engr., Standard Transformer Co., Warren, Ohio.
Pedersen, A. M., supt. of elec. maint., Hydro-Elec. Pr. Comm. of Ont., Niagara Falls, Ont., Can.
Peterson, E. F., design engr., General Elec. Co., Schenectady, N. Y.
Pingon, A. C., resident representative, Compagnie Française Thomson-Houston, C/o Int. General Elec. Co., Schenectady, N. Y.
Pinkerton, D. C., radio transmitter engr., General Elec. Co., Schenectady, N. Y.
Purnell, L. J., assoc. prof. of elec. engg., head of dept. of elec. engg., Howard University, Washington, D. C.
Putnam, T. R., Colonel, Signal Corps, U. S. Army, 25 Ridgecrest West, Scarsdale, N. Y.
Rankin, A. W., engr., General Elec. Co., Schenectady, N. Y.
Ray, A. W., mgr., service dept., Reliance Elec. & Engg. Co., Cleveland, Ohio.
Rice, J. B., elec. tech. supervisor, Tennessee Eastman Corp.-Clinton Engineer Works, Oak Ridge, Tenn.
Rich, E. A. E., elec. engr., General Elec. Co., Schenectady, N. Y.
Robinson, R. C., elec. design engr., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Rohat, N., laboratory sect. head, General Elec. Co., Schenectady, N. Y.
Rosmucker, E. A., fundamental plan engr., Ohio Bell Tel. Co., Cleveland, Ohio.
Schaevitz, H., sr. electronic engr., Baldwin Locomotive Works, Philadelphia, Pa.
Scheldorf, M. W., radio engr., General Elec. Co., Schenectady, N. Y.
Sherer, H. P., chief engr., Hertner Elec. Co., Cleveland, Ohio.
Shott, H. S., cent. sta. engg. div., General Elec. Co., Schenectady, N. Y.
Sirrine, J. E., head, J. E. Sirrine & Co., Greenville, S. C.
Tesar, J. J., asst. elec. engr., Cleveland Elec. Illuminating Co., Cleveland, Ohio.
Thomas, J. W., watch engr., Potomac Elec. Pr. Co., Washington, D. C.
Thompson, J. D., engr., General Elec. Co., Schenectady, N. Y.
Unger, J. J., elec. design engr., Elec. Products Co., Cleveland, Ohio.
Walton, A. W., protective engr., Oklahoma Gas & Elec. Co., Oklahoma City, Okla.
Walworth, S. L., district mgr., Ohio Brass Co., Pittsburgh, Pa.
Whitmer, E. W., member, engg. dept., American Gas & Elec. Service Corp., New York, N. Y.
Winstandley, M. S., elec. constr. engr., Louisville Gas & Elec. Co., Louisville, Ky.
Woods, G. B., general foreman, testing div., General Elec. Co., Schenectady, N. Y.
Young, C. W., elec. engr., General Elec. Co., Schenectady, N. Y.
Zigler, M. O., proposition engr., General Elec. Co., Schenectady, N. Y.

69 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objecting to the election of any of these candidates should so inform the secretary before September 15, 1945 or November 15, 1945, if the applicant resides outside of the United States or Canada.

To Grade of Member

Andrew, J. C. P., Callender's Cable & Const. Co., Ltd., Bombay, India
Burns, D. (Re-election), Detroit Edison Co., Detroit, Mich.
Chester, C. E., Univ. College, Southampton, England
Demorest, P. D., George H. Wahn Co., Boston, Mass.
Fickel, L. V. (Re-election), Tenn. Gas & Trans. Co., Houston, Texas
Garwood, G. T., West Hamp. Elec. Co., Ltd., Lyndhurst, England
Heymann, H., Midland Elec. Mfg. Co., Ltd., Birmingham, England
Hoffman, J. D., Gen. Elec. Co., Philadelphia, Pa.
Hoyt, J. C., Gen. Elec. Co., Philadelphia, Pa.
Isenour, G. C., Airborne Inst. Lab., Mineola, N. Y.
Joseph, B. R., Ministry of Works, London, England
Lees, H. S. (Re-election), Top O'Michigan Rural Elec. Co., Boyne City, Mich.
Linhoff, C. H. (Re-election), Gen. Elec. Co., Chicago, Ill.
McConaghy, C. M., J. B. Converse & Co., Inc., Mobile, Ala.
McJannet, D. W., Hackbridge Elec. Const. Co., Ltd., Surrey, England
Mellor, C. H., Cates & Shepard, Philadelphia, Pa.
Miller, A. L. (Re-election), Cleveland Elec. Illum. Co., Cleveland, Ohio
Moses, W. G., Rochester Ropes, Inc., Culpeper, Va.
Prentice, A. N., Ohio Power Co., Canton, Ohio
Rushing, F. C., Westinghouse Elec. Corp., East Pittsburgh, Pa.
Saviers, G. B., Westinghouse Elec. Corp., Baltimore, Md.
Sherman, R., Copperweld Steel Co., Warren Ohio
Skillington, G. E., British Oil & Cake Mills, Ltd., Hull, England
Taylor, C. R., Enfield Cables, Ltd., London, England
Van Horn, W. K., Aircraft-Marine Products, Inc., Harrisburg, Pa.
Whitmore, G. W., Whitmore Elec. Co., Miami, Fla.
Wilbur, H. R., Metropolitan Edison Co., Reading, Pa.
Woodson, R. D., Black & Veatch, Kansas City, Mo.
Yost, J. J., Beryllium Corp. of Pa., Reading, Pa.
Zimmerman, L. M., U. S. Naval Drydock, San Pedro, Calif.

30 to grade of Member

To Grade of Associate

United States and Canada

1. North Eastern

Charlton, E. E., Gen. Elec. Co., Schenectady, N. Y.
Harding, C. K., U. S. Navy Yard, Portsmouth, N. H.
Hume, J. F., Jr., Gen. Elec. Co., Schenectady, N. Y.
Mouton, R. B., U. S. Navy Yard, Portsmouth, N. H.
Stocker, J. E., Gen. Elec. Co., Schenectady, N. Y.

2. Middle Eastern

Andrews, W. T., David Taylor Model Basin, Carterock, Md.
Arthur, J. M., Duquesne Light Co., Pittsburgh, Pa.
Bunjevac, M. M., Westinghouse Elec. Corp., East Pittsburgh, Pa.
Carter, C. D., Westinghouse Elec. Corp., Sharon, Pa.
Castagna, F. C., U. S. Navy Dept., Washington, D. C.
Charny, D. P., 1522 Nedro Ave., Philadelphia, Pa.
Charlton, R. D., Gen. Elec. Co., Erie, Pa.
Day, E. H., Phila. Elec. Co., Philadelphia, Pa.
Deal, R. C. (Re-election), Gilbert Assoc., Inc., Reading, Pa.
DeCowsky, G. N., Phila. Elec. Co., Philadelphia, Pa.
Ewalt, L., Westinghouse Elec. Corp., Sharon, Pa.
Fitzsimmons, D. P. (Re-election), Union Switch & Sig. Co., Swissvale, Pa.
Flachbarth, C. T., Gen. Elec. Co., Philadelphia, Pa.
Georget, G. T., Gen. Elec. Co., Philadelphia, Pa.
Hess, W. F., Phila. Elec. Co., Philadelphia, Pa.
Kilbefler, L. D., National Cash Reg. Co., Dayton, Ohio
Knowlson, J. M., British Admir. Delegation, Washington, D. C.
Kurch, P. G., Penna. Transf. Co., Pittsburgh, Pa.
Lawrence, B. F. (Re-election), Westinghouse Elec. Corp., Bluefield, W. Va.
Lotz, C. A., Metropolitan Edison Co., Reading, Pa.
McGown, J. H., Phila. Elec. Co., Norristown, Pa.
Pomeroy, G. S., III, Metropolitan Edison Co., Reading, Pa.
Powell, R. M., Ensign, U.S.N.R., Washington, D. C.
Rose, A. S., Phila. Elec. Co., Philadelphia, Pa.
Rousey, W. I., Phila. Elec. Co., Philadelphia, Pa.
Shaw, N. C., Union Switch & Sig. Co., Swissvale, Pa.
Tabor, B., Ohio Elec. Mfg. Co., Cleveland, Ohio
Weiss, E. A., Naval Ord. Lab., Washington, D. C.
Willert, W. W., Air Way Elec. Appl. Corp., Toledo, Ohio
Zeitler, N. R., Westinghouse Elec. Corp., Sharon, Pa.

3. New York City

Bush, C. A., Weston Elec. Inst. Corp., Newark, N. J.
Chirles, R. J., Wright Aero Corp., Woodridge, N. J.
Gellrich, J. T., Fed. Tel. & Radio Corp., East Newark, N. J.
Li Calsi, J., Amer. Dist. Tel. Co., New York, N. Y.
Munson, A. J., Kellex Corp., New York, N. Y.
Willyoung, D. M., Curtis-Wright Corp., Bloomfield, N. J.

4. Southern

Bledsoe, T. A., Aluminum Ore Co., Bauxite, Ark.
Carran, R. W., Ark.-La. Gas Co., Little Rock, Ark.
MacKenzie, R. C., Watson-Flagg Engr. Co., Oak Ridge, Tenn.
Sheehan, T. R., Norfolk Shipbldg. & Drydock Corp., Norfolk, Va.
Stanhope, G. P., N.A.C.A., Langley Field, Va.
Sturman, B. J., Jr., Westinghouse Elec. Corp., Atlanta, Ga.
Winton, M. L., Tenn. Eastman Corp., Oak Ridge, Tenn.

5. Great Lakes

Anderson, A. R., Sargent & Lundy, Chicago, Ill.
Anderson, E. G., Sargent & Lundy, Chicago, Ill.
Edgar, R. B., U. S. Navy, Chicago, Ill.
Hupp, R. L. (Re-election), Gen. Elec. Co., Fort Wayne, Ind.
Jochums, W. V., Caterpillar Tractor Co., East Peoria, Ill.
Johnson, W. J., Ill. Bell Tel. Co., Peoria, Ill.
Johnts, T. E., Gen. Elec. Co., Chicago, Ill.
Lindahl, E. H., Gen. Elec. Co., Chicago, Ill.
Morris, C. H., Klaus Radio & Elec. Co., Peoria, Ill.
Parks, J. S., Fisher Body Corp., Detroit, Mich.
Poticny, J. Y., Leece-Neville Co., Cleveland, Ohio
Setzer, M. W. (Re-election), Mason & Hanger Co., Baraboo, Wis.

6. North Central

Baer, O. W., U. S. Bur. of Reclamation, Denver, Colo.

7. South West

Beard, O. K., Gulf States Util. Co., Beaumont, Texas
Jones, T. A., Lower Colo. River Auth., Buchanan Dam, Texas
Richards, D. C., Magnolia Pet. Co., Dallas, Texas
Turley, L. R., Pittsburgh Plate Glass Co., Crystal City, Mo.

8. Pacific

Brant, R. A., Sacramento Air Tech. Serv. Com., Sacramento, Calif.
Carey, J. C., Bendix Avia., Inc., Los Angeles, Calif.
Clardy, C. G. (Re-election), Rohr Aircraft Corp., Chula Vista, Calif.
Govan, E. L., Guy F. Atkinson Co., Boulder City, Nev.
Maves, W. W., A. O. Smith Corp., Los Angeles, Calif.
McCook, R. E., Ensign, U.S.N.R., San Francisco, Calif.
Palmer, E. W., U. S. Naval Dry Docks, San Pedro, Calif.
Weisinger, R. E., Consolidated Vultee, San Diego, Calif.

9. North West

Gerhardstein, C. V., C. M. St. P. & P. R. H., Butte, Mont.
Heuser, E. R., I. B. E. W., Spokane, Wash.
Kish, S. A., Northwestern Agencies, Seattle, Wash.

10. Canada

Guess, A. L., Can. Gen. Elec. Co., Ltd., Toronto, Ont., Can.
Osberg, G., Royal Can. Navy, Ottawa, Ont., Can.
Wardale, C. W., Northern B. C. Pr. Co., Ltd., Prince Rupert, B. C., Can.
Wilson, H. O., Lieut. Comdr., R.C.N.V.R., Ottawa, Ont., Can.

Elsewhere

Agarwal, S. N., Phoenix Mills, Ltd., Bombay, India
Carfrae, W. J., British Thomson-Houston Co., Ltd., Rugby, England
Chaudhri, D. P., Delhi Polytechnica, War Tech. Training Centre, Delhi, India
Jarvis, W. M., F./O., Royal Aircraft Establishment, Farnborough, England
McDonald, N. E., Parkes Mun. Council, Parkes, N.S.W., Aust.
Morris, W. A., East Anglian Elec. Sup. Co., Ltd., Britland, England
Perez Canto, F., Int'l. Gen. Elec. S. A., Inc., Caracas, Venez., S. A.
Sahgal, S. S., Lahore Elec. Sup. Co., Ltd., Lahore, India
Shukla, S. G., Ahmednagar Elec. Sup. Co., Ltd., Ahmednagar, India
Soriano R., A., C. A. la Electricidad de Caracas, Caracas, Venez., S. A.
Stieglhamber, R., Ministry of Economics, Brussels, Belgium

Total to grade of Associate
United States and Canada, 80
Elsewhere, 11

OF CURRENT INTEREST

Pursuit of Science—An Urgent Need

Among the many appeals being made these days for draft deferments of technical students and personnel in an effort to conserve potential scientific workers for the postwar world, is the special bulletin issued jointly by the Higher Education and National Defense and the National Research Council under date of May 28, 1945. This 32-page pamphlet entitled "The National Stake in the Imperative Resumption of Training for the Scientific Professions" has been prepared to assist those in and out of the government who are seeking a solution of this vital issue.

The war has not stopped or reversed the technological trend of the past few decades, namely, the expanding use of technically trained personnel in industry, and the job of reconversion as well as the job of exploiting scientific and engineering advances for the purposes of new production will fall on research and development facilities. To maintain its way of life the United States must have an expanding economy which means increased numbers of high-grade scientists and engineers with adequate facilities at their disposal. Besides, other countries are going to depend upon the leadership of the professionally trained men and women of the United States for help in becoming going concerns. Yet training in all the fields upon which the technological civilization most directly depends has practically ceased. The virtual abolition of deferment, the sharp curtailment of college military programs, and the refusal of the military authorities to assign men for scientific training have almost completely stopped the flow of men into the technological fields.

Such conclusions in this report were supported with evidence on the supply and demand for highly trained personnel in the immediate postwar years. The National Roster of Scientific and Specialized Personnel published in May 1944 a report based on a survey made through the facilities of the United States Employment Service which showed a vast unsatisfied demand for technically trained personnel ranging from 20 to 40 per cent of numbers then employed in several categories of science and engineering. The roster estimated at that time that the accumulated total need on the part of American industry was likely to be 40,000 scientists and engineers by June 1944.

Mention is also made in the report of the Purdue University's poll of more than 100 companies to determine the present situation with regard to the need of highly trained personnel (*EE*, June '45, p. 234). This showed a shortage of nearly 5,000 engineers for a small cross section of American industry alone.

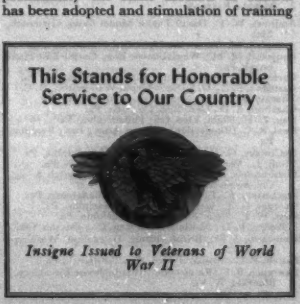
Nor is industry the only user of technically trained personnel. Federal activities in control, in counsel, in standardization, and in research have greatly stepped up the number of scientists and engineers needed in government. Stimulation of government activities in this direction after the war will be necessary to maintain research for military purposes and to revive the developments set aside by the war. Then, too, the foreign demand for equipment for laboratories, shops, power plants, and communications as a basis for reconstruction, will be urgent.

This demand will lead to a vast expansion of activities in the training of foreign students. In the large technological colleges foreign students will become a large part of the whole enrollment. Data from the Massachusetts Institute of Technology indicate that present enrollment of foreign students is twice that in prewar years and the number of applications four times as large. In the same institution the ratio of United States students to foreign students on the undergraduate level was 13 to 1 in 1939 but in 1945 the ratio is reversed and is now three foreign students to one United States student. As a further evidence of what may be expected the Indian government is sending 250 holders of national fellowships to the United States for advanced work in the sciences. These will be distributed among the universities since only a small fraction of them can be accommodated in any one institution.

Specifically in the case of engineering, the Society for the Promotion of Engineering Education reports enrollments in engineering in American colleges of something more than 110,000 in 1940–41, the last "normal" year, about 50,000 in 1943–44 and about 38,000 in 1944–45, of whom however, 17,000 were freshmen, most of whom were awaiting induction.

Contrasting practices in the United States with other countries, the report specifically refers to Russia where training in engineering and the sciences has been vastly stimulated during the war. In England, too, students in the technological branches in good standing and who are deemed by the faculties as likely to finish the training in the required time are held at the university to finish the courses. Joint Recruiting Boards with the assistance of the faculties defer students, a practice which has resulted in a steady flow of students in the critical categories at least equal to the prewar norm. In Canada approximately the same method of control has been adopted and stimulation of training in the technological branches has resulted. In the case of Australia, figures are not specifically available. However, data show that at the University of Sydney in 1930 the sciences of engineering, medicine, and dentistry accounted for 38 per cent of enrollments, and arts courses accounted for 62 per cent. In 1944, however, the arts courses accounted for only 9 per cent and the technical courses accounted for 91 per cent.

Referring to the efforts that have been made to impress Selective Service and War Manpower Commission with the seriousness of the situation, the report urges action in advance of the opening of another school year in September to provide time for institutions to set up administrative procedures for the necessary selection of students on a quota basis. The report suggests modification of existing administrative policies or legislation, and claims that a reversal of policy can be accomplished only by an aroused public opinion acting through such established government agencies as National Headquarters Selective Service System, War Manpower Commission, and the Office of War Mobilization and Reconversion.



Insigne Issued to Veterans of World War II

New Allocation for Frequency Modulation

A recent decision of the Federal Communications Commission shifts the frequency-modulation radiobroadcasting band for the United States to 88–106 megacycles. Formerly it was between 42 and 50 megacycles. Six channels are assigned to television, one between 44–50 megacycles, three between 54 and 72, and two between 76 and 88 megacycles. Facsimile is assigned the 106–108 megacycle band. The band between who are 50 and 54 megacycles is allocated for amateur use, and the space between 42 and 44, and 72 and 76 megacycles to nongovernment fixed and mobile services.

Conceding that new equipment for use in the vicinity of 100 megacycles would cost more than equipment for use in the vicinity of 50 megacycles "at least temporarily," the commission argued that the benefit to the public resulting from an interference-free service would more than outweigh the slight increase in initial cost.

The testimony of the engineers of the Federal Communications Commission and especially of K. A. Norton (A '41) formerly of the Federal Communications Commission and now a civilian employee of the War Department, was challenged by many objectors at the hearings prior to the rendering of the decision. Among the latter were H. H. Beverage (M '34) associate director of the laboratories of the Radio Corporation of America, New York, N. Y.; C. R. Burrows (M '33) radio research engineering department of the Bell Telephone Laboratories, Inc., New York, N. Y., and G. W. Pickard (F '12) director of research, American Jewels Corporation, Attleboro, Mass.

Stresses Responsibilities of Engineers

The part played by American colleges in training more than 50,000 men to serve as naval officers was called an important factor in winning the war, by Captain Arthur S. Adams, United States Navy (retired) in an address at the commencement exercises of Stevens Institute of Technology, Hoboken, N. J., on June 27. Captain Adams has been in charge of the V-12 training program and is provost-elect of Cornell University, Ithaca, N. Y.

Captain Adams said that the integrity of the individual, and his assumption of personal responsibility for being a human being, were the most important assets that a democracy could have. In addition to their professional proficiency, engineers, Captain Adams emphasized "must constantly be vigilant to recognize their personal responsibilities as citizens, if we are to keep this country great." He said that many engineering students are prone to dismiss all nonengineering matters as uninteresting and unimportant. Pointing out that in order to succeed in engineering, the student must have a capable intelligence, a balanced judgment, and a capacity for hard work, he said that with these qualities he is certain to be able to make a significant contribution to public thinking.

He further explained that a truly educated man, and especially a technically educated man, should concern himself with, and feel responsible for, his development along social, political, and economic lines, just as he does along professional lines, and must make it his business to be informed of all matters affecting the public interest.

Past President Powel in European Assignment

Charles A. Powel, junior past president, AIEE, and manager headquarters engineering departments, Westinghouse Electric Corporation, East Pittsburgh, Pa., was selected by the War Department to be chief of the electrical and radio branch in the United States Group Control Council for Germany. According to the Army his immediate task will be the surveying of the facilities in the American zone of occupation, the establishing of controls under which German industries will be permitted to revive, and the seeing to it that these industries are so organized that they cannot become potential producers of war material.

Advances Made in Synthetic Rubber

Production of synthetic rubber has reached a grand total of 1,400,000 long tons since the start of the Government's program. This fact is contained in a study entitled "Report on the Rubber Program, 1940–45," by S. T. Crossland, executive vice-president of the Rubber Reserve Company, a subsidiary of the Reconstruction Finance Corporation. Production of 737,000 tons for the year 1944 was greatly in excess of the largest amount of natural rubber consumed in the United States in any prewar year. On quality the report states that tires of passenger-car size are being built out of substantially 100 per cent synthetic rubber. The use of butyl rubber in the manufacture of inner tubes and of other products where pneumatic (air retention) properties are important, has been successful and is expanding.

OTHER SOCIETIES •

Engineer Describes Development of Electric Tank Turret

Development of a new electric drive for the turret of the General Sherman tank, with acceptance tests completed on the eve of Pearl Harbor, was described by Stanley J. Mikina (M '41) electromechanical research engineer of the Westinghouse Electric Corporation, East Pittsburgh, Pa., before a recent section meeting of the American Society of Mechanical Engineers in Chicago.

The project of developing an electric turret-traversing mechanism for tanks was undertaken by Westinghouse at the request of the Army Ordnance department in February 1941, Mr. Mikina said. Its object was to supply the Army with another source of supply of turret drives for the new M4 tank, in addition to the hydraulic drives then employed.

In his illustrated paper, Mr. Mikina described in detail the methods of developing the new mechanism. It was felt at the Westinghouse laboratories that by applying principles of electric control learned in peacetime applications to steel-mill tension regulators and positioning systems, it would be possible to develop an electric drive for tank turrets that would in some respects be superior to the established hydraulic drives.

By utilizing the previously developed Silverstat control, together with gyroscopic means for elimination of unstable oscillations, a positionally regulated drive was created which enabled the tank gunner to point the turret gun over the full circle of travel with the same facility as if he were aiming a light rifle. A force of two pounds on the handle of the control handwheel was sufficient to move a heavily armored turret weighing 12,000 pounds.

Synthetic Fuels Made by Bureau of Mines

To a special Senate committee investigating petroleum reserves, M. V. Straus, Assistant Secretary of the Interior, recently said that the Bureau of Mines was making synthetic fuels and "good" gasoline, that was driving internal-combustion engines. He declared that the completion of the $30,000,000 synthetic fuels demonstration program authorized by Congress would go a long way toward the establishment of a synthetic fuels industry and independence for the United States in natural resources.

New Officers of Illuminating Engineering Society

Albert F. Wakefield, president of the F. W. Wakefield Brass Company, Vermilion, Ohio, has been elected president of the Illuminating Engineering Society.

Mr. Wakefield has been active in the society for more than 25 years, serving on numerous nontechnical committees before his election as vice-president in 1943. He is a former chairman of the commercial lighting equipment section of the National Electrical Manufacturers Association, and has served on both the incandescent and fluorescent lighting equipment advisory committees of the War Production Board, Washington, D. C.

Mr. Wakefield is as well known in marine circles as he is to the lighting industry. He has been active in the development of harbors and refuge for small craft on the Great Lakes and has been an influence in the development of water areas for recreational purposes.

The Illuminating Engineering Society was established in 1906 to encourage the broadening of scientific study as a basis for better illumination.

Other national officers elected by the Illuminating Engineering Society include L. E. Tayler of the Detroit (Mich.) Edison Company as general secretary; Bruce J. Jensen, Public Service Electric and Gas Company, Newark, N. J., as treasurer; and R. W. Staud, Benjamin Electric Manufacturing Company, Des Plaines, Ill., as vice-president.

Members Active in Electronics Club, Fort Worth Electronics Club concluded its activities for the year with the June meeting at which J. L. Caudry (A '45), Texas Electric Service Company, Fort Worth, Tex., gave a talk on high-frequency heating. Another feature of the meeting was a reel of sound film which was shown to members and their guests through the courtesy of the General Electric Company, Schenectady, N. Y., on "Sight-seeing at Home." Among officers elected were: P. G. See (A '44) Consolidated Vultee Aircraft Corporation, vice-president, and W. H. Farrington (A '41) Texas Electric Service Company, secretary-treasurer. Directors included: W. C. Fowler (M '36) Sangamo Electric Company, Springfield, Ill.; H. F. Spreen (A '40) Texas Electric Service Company; and J. L. Caudry.

ASTM Approves Materials. At a one-session business meeting held in New York, N. Y., on June 27, the American Society for Testing Materials, Philadelphia, Pa., authorized the adoption as formal standard of some 35 tentatives previously published and the adoption of some 40 revisions in existing standards. The approval of new tentative specifications and tests is an indication of new work resulting from the technical committees' deliberations. These cover tests for resistance of traffic paints to abrasion; for producing films of uniform thickness on panels; analyzing petroleum sulfonates, and several new tests covering paper and paper products. The

new officers of the society include J. R. Townsend, materials engineer, Bell Telephone Laboratories, Inc., New York, N. Y., as president; and T. A. Boyd, head, fuel department, research laboratories division, General Motors Corporation, Detroit, Mich., as vice-president.

Physical Society Meets. The 267th meeting of the American Physical Society was held in the physics department of Stanford University, Stanford University, Calif., on July 14, 1945. Nineteen contributed papers and two invited papers were given.

HONORS

Paul Clapp Receives Marston Award

Paul S. Clapp (A '18) vice-president of the Columbia Gas and Electric Corporation, Columbus, Ohio, was presented the Marston Medal by the Iowa State College, Ames, at its graduation exercises on June 16.

The Anson Marston Award, consisting of a suitable gold medal, was established in 1938 by Iowa State College through the inspiration and generosity of Anson Marston, dean emeritus of engineering. It is awarded, not oftener than once each year, to an engineering alumnus of at least 30 years' standing for achievement in engineering in a broad field. The award is made by a board consisting of four alumni, a representative each of the American Society of Civil Engineers, American Society of Mechanical Engineers, American Institute of Electrical Engineers, and the American Institute of Chemical Engineers, and the dean of engineering who will serve as ex-officio chairman of the board.

An account of Mr. Clapp's professional career is given in the "Personal" section of this issue.

Honored for Advancing Industrial Science. In tribute to his leadership in advancing industrial science, Clyde Williams, director of Battelle Memorial Institute, Columbus, Ohio, was presented the degree of doctor of science at recent convocation ceremonies of the Case School of Applied Science, Cleveland, Ohio. The degree was presented by Doctor William E. Wickenden (F '39) president of the school who cited Mr. Williams' accomplishments in research administration and in directing the activities of the war metallurgy committee of the National Academy of Sciences and the National Research Council.

Yank Soldier Wins Suggestion Award. Melvin Jacobson, a private in the United States Army, who is on military leave from the Westinghouse Electric Corporation, East Pittsburgh, Pa., sent a report to the plant suggestion committee about an unusual lamp socket he had found in Germany. The description was turned over to engineers of the company who found it impractical for American use. However, the committee awarded Private Jacobson $15 for his thoughtfulness and his desire to assist in the productive effort at home. The socket is made of plastic and has a small alloy current contact.

War Worker Earns Top Westinghouse Award. The highest award for suggestions ever made in the 35-year history of the suggestion system of the Westinghouse Electric Corporation, East Pittsburgh, Pa., was presented recently to a retired real estate operator who entered war work after Pearl Harbor and was engaged at the lamp division's electronic tube plant at Bloomfield, N. J. The suggestion resulted in an estimated annual saving of $30,630 to the nation's war effort.

RESEARCH

Scholarship Fund Honors Ex-President Swope

To assist in higher education and fundamental research work in scientific and industrial fields, a fund of $400,000 has been set aside by the directors of the General Electric Company, Schenectady, N. Y., to be known as the Gerard Swope Foundation. Mr. Swope (F '22) served as president of the company from May 1922 until the end of 1939, and for an additional two years in 1942–44 he returned to head the company when C. E. Wilson (A '16) now president, was acting as executive vice-chairman of the War Production Board. The directors announced that the new foundation was created as an expression of appreciation and as a means of making this appreciation of enduring and constructive benefit to the company and to the electrical industry.

DISPOSITION OF FUND EXPLAINED

The income of the foundation will be utilized in the following ways:

1. In granting loans or scholarships to employees and to the children of present or former employees of the company and its affiliated companies, to help them pursue their work in any field of study and in any approved university, college, or technical school in the United States.

2. In granting graduate fellowships to the same classifications of individuals to be used by the recipient for graduate work in industrial management, engineering, the physical sciences, and in any other scientific or industrial field.

3. In granting loans, scholarships, or fellowships in any of the above fields to any other person that may be deemed worthy of assistance.

4. In granting graduate fellowships, to make contributions to the university, college, or technical school to help in defraying the cost of equipment and material, especially needed in connection with a research project.

Applicants for loans, scholarships, and fellowships will be considered not only from the standpoint of academic attainment and financial needs, but also as to character and personal qualifications.

It is planned to make a statement of awards under the foundation in each of the company's annual reports. Details of administration are to be announced later.

Research Laboratories at Pennsylvania State College

The United States Navy has completed arrangements for the establishment of two permanent ordnance research laboratories which will be in operation by fall at the Pennsylvania State College, State College, Pa., under a Bureau of Ordnance contract. The establishment of these laboratories is in keeping with the bureau's broad policy of forming research affiliations with educational institutions to further development of naval weapons and for educational purposes in the postwar period.

The Ordnance Research Laboratory, dealing with underwater ordnance, will be housed in a new building now under construction on the campus. The work will be a continuation of the research formerly carried on by the Underwater Sound Laboratory at Harvard University which has been sponsored by the Office of Scientific Research and Development, with technical direction from the Bureau of Ordnance.

Eric A. Walker (M '41), who was in charge of the Ordnance Research Division at Harvard, will direct the new laboratory. A brief account of Doctor Walker's career is given in the "Personal" section of this issue.

Assistant directors of the Ordnance Research Laboratory will be A. N. Butz, Jr. (A '45), who formerly operated a private electronics research laboratory, R. R. Thompson, formerly associated with Bell Telephone Laboratories and the Humble Oil and Refining Company, and Doctor Harvey Brooks. All of these men are now affiliated with the Harvard University Laboratory. A staff of approximately 125 scientists, technicians, and clerks will be transferred from the Harvard Laboratory to the new unit. In addition to the work that will be undertaken on the campus, this laboratory will also operate a calibration station at the Black Moshannon Lake, approximately 20 miles from State College, and a test station at Fort Lauderdale, Fla.

The Petroleum Refining Laboratory has been in operation for approximately 16 years at The Pennsylvania State College. During the present war emergency, it has also been under the sponsorship of the Office of Scientific Research and Development. The plan is for this laboratory to continue with the petroleum research under a direct contract with the Bureau of Ordnance, including special work for and technical reports to the other services. Doctor M. R. Fenske will continue as director of the Petroleum Refining Laboratory, a position which he has held since it was established. The staff of this laboratory includes more than 50 chemists, chemical engineers, and technicians.

The Ordnance Research Laboratory has been placed under the School of Engineering by The Pennsylvania State College, and the Petroleum Refining Laboratory is under the School of Chemistry and Physics.

New Research Directory in Prospect

The eighth edition of "Industrial Research Laboratories in the United States," the directory of the National Research Council, Washington, D. C., is being compiled.

Laboratories in the field of electrical engineering are invited to send for questionnaires. Laboratories which reported in 1940 have had their printed statements sent for revision. There is no charge for the inclusion of a statement regarding a laboratory, and no obligation is incurred in furnishing data.

The seventh edition appeared in 1940, and contained information on industrial research laboratories of 2,264 companies and their subsidiaries. The term "research" for the purpose of the directory is construed as including investigations looking toward the improvement of products, or the reduction of cost of manufacture as well as fundamental research and applied research. It does not apply to laboratories concerned only with commercial testing.

Science Points the Way to a Better Life

"Men now living may well see the day when a nation's true hidden wealth will not consist of her natural raw materials, but rather consist of her men of science and their laboratories." With this conviction John W. Thomas, chairman of the Firestone Tire and Rubber Company, New York, N. Y., addressed the American Institute of Chemists meeting in Columbus, Ohio, on May 11, 1945. Doctor Thomas expressed the opinion that the next 50 years would bring changes and improvements in the way of life that will overshadow the accomplishments of the past 50 years. But, he claimed that permanent peace is the requisite for a full life and that science may be the chosen arbiter to bring this condition about. The approaching evolution in present-day living will depend on the intensity and earnest application with which untrammeled scientists pursue their work. Doctor Thomas argued that if every nation could possess within its boundaries all of the raw materials it needs to live and to prosper there would be little if any cause for wars. Though this may seem like a dream it was, he said, a dream that can be realized at least in part through the medium of scientific research. He claimed that the scientific investigator does not know the meaning of "it can't be done." He only knows that "it never has been done." And just as the same scientific spirit conquered the forces of evil it can also be applied to making life better for all mankind.

Russia Honors Science. The 220th anniversary of the Academy of Sciences founded in 1725 by a decree of Peter I, has been celebrated by the Russian government. Invitations to a festival were sent to a large number of British, American, and other scientists to attend a series of events in Moscow and Leningrad from June 15 to June 28. Among the specialists invited by the Russian government to make the trip in a specially provided Soviet plane were E. U. Condon (M '44) associate director of the research laboratories of the Westinghouse Electric Corporation, East Pittsburgh, Pa., and A. Nadai, consulting mechanical engineer of the corporation. Several papers were presented at meetings and discussions were held.

Scientific Tolerance—Major Duty to Society

A plea for scientific research in the days immediately after the war was vehemently voiced by H. E. Fritz, director of research, B. F. Goodrich Company, Akron, Ohio, speaking before the recent annual conference of the American Welding Society in Cleveland, Ohio, on the subject "Research an Irresistible Force." Claiming that nature's treasure chest was the only safe frontier left for the United States to exploit, he said the process meant "an attempt to know more, about more, so that we can have more, more of the time." This search resulted in an overflowing reservoir of fundamental new knowledge which was the best insurance policy of freedom for any freedom-loving nation.

Scanning the accomplishments of science between the World War I and II he proved conclusively that there is no phase of civilization today that is untouched by science and research. He warned his listeners that research and trial must be continued if the standard of civilization in the United States is to be sustained, and urged encouragement to those people who will be plowing new fields. To promote tolerance and comprehension for those new revelations which the human mind would uncover is a major duty to society.

EDUCATION. . . .

Columbia University Blazes New Trails. Six regional organizations will be initiated at Columbia University, New York, N. Y., for the purpose of studying the life and thought of principal areas of the world and understanding the social, economic, and political problems of peoples who will play an important role in shaping the world of tomorrow. The Russian Institute, established through a grant of $250,000 from the Rockefeller Foundation, will be the first to be opened on July 1, 1946. The British Commonwealth of Nations, East Asia, Latin America, France, and Germany will constitute the other five institutes. These institutes will be staffed by groups of outstanding scholars who have specialized in one of the pure or applied sciences of human conduct with special reference to some specific geographical area. An announcement has also been made of the formation of a School of International Affairs to function in close cooperation with the institutes. The curriculum of this school is designed to train graduate students for service in technical and managerial posts in government agencies maintaining a foreign service.

Wanted—Building for Engineering Students. A $400,000 money-raising campaign to defray the cost of another four-story wing on the Engineering Building at the University of Southern California, Inglewood, is in progress. The present building was built in 1939 to accommodate 350 students, and it now has 750 full-time day students on its rolls and is used by 2,200 evening-school students including those taking war-training courses. Though construction on two small one-story buildings has been started to make room for research laboratories these additions will not relieve the need for the engineering wing.

Refresher Courses at Houghton. The Michigan College of Mining and Technology, Houghton, has established a correspondence-course program intended primarily for former students, especially those in the armed services. It will consist of 60 courses. One fourth are noncredit refresher courses; the rest carry credit. They are being offered by nearly all departments, both service and degree-granting. It is expected that instruction will begin in many of the courses in the early fall. The college has also established a public relations division which became operative on July 1.

Flying Fortress for Nonflight Use. A $330,000 "Flying Fortress" has been sold under the Reconstruction Finance Corporation's educational distribution program to the Williamsport, Pa., Technical School for $350 for use as a ground aeronautical laboratory. The airplane is reputedly a veteran of many bombing missions over Europe.

Liberalizing General Science. A new general science and arts course has been established at the Colorado State College of Agriculture and Mechanical Arts, Fort Collins, Colo., which will permit students to elect 40 per cent of their courses. It is expected that most students will, under faculty guidance, select some specific scientific interest in their senior year. The new program will appeal to pre-medical students or those looking forward to graduate work.

Electron Microscope at McGill University. A Radio Corporation of America electron microscope has been installed at McGill University, Montreal, Quebec, Canada, for extended work in physics, biology, medicine, chemistry, and metallurgy. Scientists are using the instrument for war research, and important peacetime studies are also projected. Using electrons instead of ordinary light the electron microscope has a resolving power so great that a magnification of 100,000 diameters can be realized.

Stevens Institute Camp Reopened. Ralph Bown (F '41) director of radio and television research, Bell Telephone Laboratories, New York, N. Y., was one of the lecturers at the Junior Camp of the Stevens Institute of Technology at Johnsonburg, N. J., at its 13th annual session from July 15 to July 28. The Stevens Junior Camp was reopened for the first time since 1942. The two weeks' session was devoted to helping young men of high-school and preparatory-schoolage determine the vocation for which they are best fitted. Guest lecturers in the various branches of engineering described the work of their respective fields.

JOINT ACTIVITIES

ASA Broadens Scope for Postwar Work

Changes have been made in the constitution of the American Standards Association that will enable it to meet more fully the needs of government and industry in the postwar period. The national trade, technical, and governmental groups that make up the association have ratified the changes, the principal one of which will remove present restrictions limiting the work of the association "to those fields in which engineering methods apply" so that the organization can in future handle any standard or standardization project which is in the field of engineering or consumer goods or in any other field which deserves national recognition.

Discuss Screw Thread Standards. Technical men from the Army and Navy, as well as from the automobile, aircraft, machine tool, electrical, and other industries met in New York, N. Y., recently under the auspices of the American Standards Association to work on a series of standards for the threaded parts that go into aircraft engines, pipes for aircraft fuel lines, aircraft control mechanisms, instruments, and miscellaneous industrial applications. The purpose of these meetings was primarily to consolidate the American point of view before the expected gathering of British, American, and Canadian technical experts at Ottawa, Ontario, Canada, in the fall under the auspices of the Combined Production and Resources Boards of which all three countries are members. The American Society of Mechanical Engineers and the Society of Automotive Engineers are joint sponsors of the ASA peacetime project on screw threads and are cooperating closely in the war work.

WAR PROGRAM

Invisible Dye Aids Tropicalization

The United States Army Signal Corps Laboratories have recently developed an invisible dye to facilitate inspection of treated equipment. This invisible or fluorescent dye is mixed with the lacquer which is sprayed over radios, field telephones, and other communication equipment to prevent inroads of fungus and moisture.

All the lacquers, whatever their content, are colorless, or nearly so, in order that the numbers and the identification marks on the various instruments may be plainly read through them. The result is that it is not easy, by ordinary vision, to check on the thoroughness and evenness of the spraying. To aid in this, a special lamp, strong in its emission of ultraviolet rays and equipped also with a deep purple filter, comes to the aid of those responsible for inspection. This lamp, directed upon the equipment, picks up the ultraviolet dye in the lacquer (though it is quite invisible to the eye) and shows with any imperfections in the spraying.

A simple field expedient which can be used in war theaters to discover weak spots in the spraying is to try writing upon lacquered equipment with an ordinary pencil. Wherever the pencil glides as if on glass the spraying has been adequately done. If it "starts to write" it has found a weak spot. Often the tropicalization of communication equipment can then be completed in the field.

American Contributes to Pipeline Feat. Manufacture of materials in the United States substantially aided in the construction of 20 emergency oil pipelines across the English Channel by British engineers according to Colonel H. R. Lynn, technical and military adviser to the British Petroleum Warfare Department. Colonel Lynn said that much credit for the project should also be given to Doctor L. M. Goldsmith (M '26) chief engineer of the Atlantic Refining Company, Philadelphia, Pa., for his advice during preliminary work on laying the pipelines. The Channel operation was called "Pluto" by the British, meaning pipelines under the ocean. Doctor Goldsmith is also consultant to the United States War Department. His services were loaned to the British at the request of Major General Sir Donald Banks of the British Petroleum Warfare Department.

Engineers in Training for Pacific War

In rehearsal for the roles they will play in building bases for carrying the war to Japan, members of the Army Engineers Corps are undergoing a course of intensive study and training at the East Pittsburgh, Pa., plant of the Westinghouse Electric Corporation. Under the supervision of Lieutenant John A. Schaefer, of Fort Belvoir, Va., the service engineers are acquiring information on installing, operating, and maintaining electric generators, transformers and switchgear destined to bring light and power to military installations where no previous power existed in the Philippines, Iwo Jima, and other far-off Pacific battlegrounds. The 53 military students, constituting the first group, possess some engineering background and all have been chosen because of particular aptitude in that field. The course includes classroom lectures and discussions, demonstrations in shop and laboratory, a visit to the Westinghouse plant at Sharon, Pa., to study transformers, and the actual handling of power equipment.

The course of instruction at the East Pittsburgh plant is being co-ordinated by the Westinghouse student training department.

Radio Receivers For Enlisted Men Overseas

To provide entertainment and to aid morale of enlisted men overseas, more than 50,000 sets of a new radio receiver, *R*-100/URR, are being distributed to troops at overseas installations. Procurement orders call for manufacture of over 100,000 sets which will be issued on the basis of one set to every 50 enlisted men except where isolated units number less than 50. The sets are not for use in the United States nor will they be available to officers' clubs nor groups of officers overseas until recreational needs of enlisted men are fully met.

Controls are much simpler than those in other Army radios. The antenna is reeled into the back of the cabinet in such a way that it can be quickly unwound and slung over the nearest tree branch. The control panel is recessed far enough so that nothing protrudes, and the sets can be stacked and shipped without danger of damage. A built-in loudspeaker and headset jacks accompany the receiver, and flexible antenna wire is provided as a part of the set. The entire receiver is fungus and corrosion resistant. Transformers and chokes are potted for protection against the humidity of the tropics. The steel cabinet is light in weight but will withstand heavy shocks. The receiver provides reception of medium and short-wave broadcasts. It operates from self-contained batteries or on direct or alternating current. It is adaptable for use with several different types of standard Signal Corps batteries. This new radio receiver was developed and standardized by the Signal Corps.

Enemy Patents Licensed to Americans. Of the 45,000 patents and patent applications seized by our government from enemy aliens and nationals of occupied countries, 9,366 of the inventions have been licensed to 760 American firms and individuals. Included in the block are about 29,000 of German origin, 7,800 French, 1,800 Italian, 1,300 Dutch, 1,200 Japanese, and the remainder miscellaneous enemy and enemy-occupied origin. This statement was made by Dexter North, chief of patent administration of the Alien Property Custodian's office, Washington, D. C., who turned over the working drawings on this collection to the Midwest Research Institute, Kansas City, Mo., as a repository for the seized patents. The Kansas City institute, a nonprofit scientific research organization was established and is controlled by leaders of the Middle West to industrialize the mineral and agricultural resources of the region. Many of the inventions represent some of the finest achievements of research talent in Europe. Rights for lifetime use of patents of enemy countries may be secured for a fee of $15. A similar fee is charged by the Alien Property Custodian for use of patents originating in nonenemy and occupied countries, plus a small royalty. The file is accessible at all times to manufacturers, agriculturists, educational institutions, and others.

POSTWAR

War Memorial for Cleveland. A War Memorial for the heroes who sacrificed their lives in World War II will be built on the Mall in downtown Cleveland, Ohio, as soon as materials become available. This project is being sponsored by the *Cleveland Press*, which is currently backing a drive to raise $100,000 for a fountain, for which prelimi-

nary designs have been made by the lighting division, of the Westinghouse Electric Corporation, East Pittsburgh, Pa. Plans call for a pool approximately 130 feet in length by 110 feet in width with cascading water displays grouped in an elevated basin and centering around a single solid jet rising to a height of 70 feet. Lighting effects will vary, as will combinations of water displays through a cycle lasting 30 minutes. Names of the more than 3,000 servicemen from the greater Cleveland area who died in service will be perpetuated on bronze plates around the top of the main pool wall. All water displays will be illuminated at night by means of specially designed floodlights submerged in the water of the basin and the pool. Lamps as large as 1,500 watts would be used to obtain the required intensities. The floodlights equipped with color lenses producing red, amber, green, blue, or white light will be separately controlled by means of electrically operated dimming equipment, whereby one color is gradually blended into the next throughout the cycle.

Advice for the Veterans. A Veterans' Advisement Center is to be established at the Rochester, N. Y., Institute of Technology. This center, one of four in western New York, will work in conjunction with the Rochester Institute's counseling center which has operated as a clinical counseling and testing service for more than four years.

INDUSTRY . . . . .

Boom in Television Predicted. Analyzing the immediate and long-range prospects of the radio industry in the United States, Brigadier General David Sarnoff (M '23) president of the Radio Corporation of America, New York, N. Y., predicted recently that television will equal the expansion of sound broadcasting after World War I. He said that some 200 new types of electron tubes had been developed by the corporation in the war years, and that when civilian production gets the go-ahead signal the making of home radio and phonograph sets will get under way in 60 to 90 days and television in nine months to a year. He further stated that substantial reduction in the size of many models, including the "personal" type, will be possible through use of miniature electron tubes. It is his opinion that the opening of the microwave region of the radio-frequency spectrum points to many new services in the "citizens radio" field, such as personal radiotelephone equipment resembling the war aid, the "handie-talkie."

Newsletter on Electronics Announced. *Electron*, a newsletter of electronics and television, is a new weekly periodical published by Legend House, Inc., New York, N. Y.,[2] and designed to keep executives and engineers informed of the latest developments in electronics and television. This publication is under the editorial supervision of Harold Prince, former editor of *Bakelite Review*.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Depletion of Ranks of Scientific Students

To the Editor:

During recent years the number of students in electrical engineering has dropped precipitously in spite of the accelerated programs and will drop still further when the full impact of all factors is realized. Figure 1, compiled from tables given at various times in the *Journal of Engineering Education*, illustrates this point.

The fact that the number of doctoral candidates and doctoral degrees granted has dropped to practically zero has been well emphasized in other publications,[1,2] but for further emphasis the figures are present again in Figure 2.

Both of these facts show the influx of new engineering man power has been depleted seriously during the national emergency.

To these two other factors must be added. First, a great many of the young men graduating in electrical engineering or allied sciences have been inducted into the Armed Forces where, although some have been given additional scientific training, it is hardly to be expected that this has been of great use in furthering their professional growth. Moreover, many will have been introduced to nonscientific pursuits in which they will remain after the emergency, because they will wish to make use of any special training, or are unwilling to undertake the training necessary to claim their expected place in the profession.

A somewhat more specialized depletion has taken place in the ranks of engineering teachers, since many of them have been drafted from their normal teaching pursuits to work in scientific laboratories sponsored both by industry and government agencies and now, as the emergency ends, do not intend to return. This is not an unqualified loss to the profession as a whole, but it will deplete the number of competent engineering teachers and reduce the quality of the neophyte engineers, since many of the best teachers have been so diverted.

There is no question concerning the value of the scientists' contributions to the war effort. No one will question that engineers, working at their own profession as civilians and in many cases in their permanent jobs, have contributed more to the successful prosecution of the war than they might have done if drafted indiscriminately into the Armed Forces. Engineers' have contributed many new ideas for new weapons, assisted in their development and test, and checked their use by the Armed Forces. Their tremendous contribution has been evident in the production records established by this country. Indeed, in an address before the AIEE in May 1941, a representative of one large manufacturing company predicted that it would take 14 workers on the home front to support one soldier in the field. This has been disproved, since this country with about 60,000,000 workers has supported an Armed Force of approximately 11,000,000 men and has supplied tremendous amounts of equipment to the Allies. Such figures only reinforce one's opinion of the effectiveness of a few hundred thousand engineers and production specialists working at their own profession.

Now half of the war is ended, and we can look forward with considerable certainty to a successful finish within the next year or so. Then will begin a period of growth and reconstruction which will tax our technical man power to the utmost. Our allies, Russia and Great Britain, long have recognized this situation and, although much harder pressed than we ever have been, they have made a

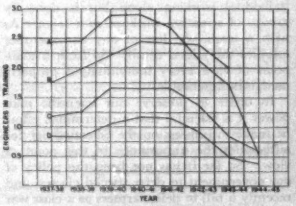


Figure 1. Engineers in training

A—Number of electrical engineering seniors (× 1,000)
B—Number of electrical engineering degrees (× 1,000)
C—Number of electrical engineering students (×10,000)
D—Number of engineering students (×100,000)

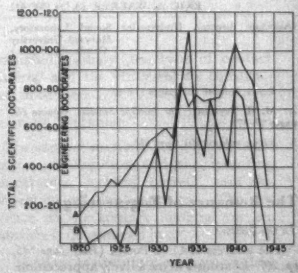


Figure 2. Doctorates per year

A—Doctorates in science (chemistry, mathematics, physics, and engineering)
B—Engineering doctorates

determined effort to preserve the continuity and strength of their technical resources. An effort has been made to keep a continual flow of technical students through the colleges and technical institutes. Their scientists and engineers have been encouraged to continue their research throughout the war and have not been drafted to bear arms.

In this country we have approximately 100,000 scientists, engineers, and technicians. If all were drafted, the addition to the Armed Forces would not be great. Yet at this late date there is a very serious threat to the further curtailment of all scientific personnel.

The National Roster of Scientific Personnel and the Office of Scientific Research and Development are authorized to certify research workers for deferment by the local boards. However, these agencies must agree to specific limitations upon the total number of certifications that will be made and that there will be definite limitations on the type of persons to be certified. Under these regulations the research laboratories and colleges are asked to list their personnel in order of decreasing importance and then are asked to state why each person is essential. Obviously it is difficult to explain why a young man but a few years out of college and with no formal training period after a bachelor of science degree is essential. The Selective Service officials fail to realize that reseach work no longer is carried on by a long bearded individual working alone but is done by groups of scientists working as a team. As with a team, the loss of any one member crippies the efforts of all. So from a team point of view every individual, if properly used, is indispensable.

In order to preserve our scientific man power it is essential that a determined effort be made to impress on the Selective Service authorities the importance of this point of view. So far it has not been the policy of our government to defer special classes, and recently a bill to defer farmers as a class was defeated. But perhaps the time has arrived to abandon this principle and defer scientists as a class because of the importance of scientific research and engineering, both through the remainder of the war and in the following reconstruction period. Representation has been made to the War Manpower Commission and Selective Service Director by several scientific societies.[3] Is it not time that the AIEE joined this effort?

ERIC A. WALKER (A '34, M '41)

(Associate director, Underwater Sound Laboratory, Harvard University Cambridge, Mass.)

REFERENCES

1. *Science*, volume 101, pages 172–8.

2. **M. H. Trytten.** *The Scientific Monthly*, volume 60, pages 37–47.

3. *Science*, volume 101, page 486.

The Romance of Engineering

To the Editor:

The address of C. A. Powel (*EE, June '45, pp. 207–10*) arouses in me a lively appreciation. In my more than 50 years of engineering it has been my good fortune never to lose the wonder aspect out of my life. He rightly emphasizes the seemingly permanent continuance of engineering subjects of intense interest. To the extent that young men, as they grow older, have and retain the ability to see into the inside of things, to that extent they will retain the fresh interest of youth even as long as they live. A Stillson wrench is not merely a wrench, the rubber on a wire is not merely an insulation, a storage battery is not merely lead plates in acidulated water. Each has back of it a line of noble development, each has in it a world of natural laws and ingenious combinations of laws.

For the sake of the young men we are glad for that address.

A. B. SMITH (A '04, F '22)

(Chief research engineer, Associated Electric Laboratories, Inc., Chicago, Ill.)

NEW BOOKS • • •

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; these and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in these columns should be addressed to the publisher of the book in question.

Conference Leader Training. By Edward S. Maclin and Paul T. McHenry. National Foremen's Institute, Inc., Deep River, Conn., 1945. 80 pages, 5½ by 8 inches, cloth, $2.50.

A work book in the conference method, this manual gives a concise listing of the needs for leadership training and presents in practical form the various devices used in dealing with different situations, as well as the techniques involved in planning and leading discussions. Thirty topics are suggested for conference discussion which cover pretty thoroughly the life of the worker in a plant.

How to Handle Labor Grievances. By John A. Lapp. National Foremen's Institute, Inc., Deep River, Conn., 1945. 294 pages, 5½ by 8 inches, buckram, $4.

The history of the development of grievance plans, the operation of grievance systems, and the problems which have resulted, make up the subject matter of this book. The work is the outcome of the experience of the author in handling arbitrations of labor grievances and in formulating and interpreting collective bargaining contracts.

Paper and Paperboard. Sponsored by ASTM committee D-6 on Paper and Paper Products, American Society for Testing Materials, 260 South Broad Street, Philadelphia, Pa., 1944. 108 pages, illustrated, 9 by 6 inches, paper, $1.50. (ESL.)

The four parts of this report cover respectively: general considerations and the nature of paper properties; the action of water on paper and its significance; definition of terms, nomenclature, and properties of various classes of paper and paperboard; and a discussion of commonly used tests applied to paper and paperboards and their significance. A complete list of ASTM and Technical Association Pulp and Paper Industry test methods is included.

Universe Around Us. By Sir J. Jeans. Fourth edition revised and reset. University Press, Cambridge, England; Macmillan Company, New York, N. Y., 1944. 297 pages, illustrated, 8½ by 5½ inches, cloth, $3.75.

This book contains a brief account in simple language of the methods and results of modern astronomical research, both observational and theoretical. Special attention has been given to problems of cosmogony and evolution and to the general structure of the universe. This fourth edition has been largely rewritten in the light of recent advances, such as the application of the physics of atomic nuclei to various stellar phenomena.

English-French Comprehensive Technical Dictionary of the Automobile and Allied Industries. Compiled by L. L. Sell. McGraw-Hill Book Company, Inc., New York, N. Y., and London, England, 1932, reprinted. 768 pages, 7½ by 5½ inches, fabrikoid, $8. (ESL.)

This dictionary contains more than 150,000 English and French technical terms used in the automobile and allied industries. The list is a very detailed one, covering many phrases as well as words, and both English and American usage have been considered. As many of the terms apply equally to all branches of mechanical engineering, the dictionary will be useful to translators in a wider field than the title indicates.

With the Watchmaker at the Bench. By D. de Carle. Fourth edition. Pitman Publishing Corporation, New York, N. Y., and Chicago, Ill., 1944. 239 pages, illustrated, 7 by 5 inches, cloth, $3. (ESL.)

The early chapters describe the watchmaker's equipment and methods for training the beginner in its use. Succeeding chapters deal with the examination of the movement, the manufacture and repair of watch parts, and cleaning methods. The final chapter covers briefly the use of the watchmaker's lathe. The book is intended to be of use in any branch of fine mechanics, such as aircraft instrument making.

PAMPHLETS • • • •

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

Geiger-Counter Spectrometer for Industrial Research. By H. Friedman. North American Philips Company, Inc., 100 East 42d Street, New York, N. Y., 8 pages.

Vector Chart for Determining Capacitor Kvar. Cornell-Dubilier Electric Corporation, South Plainfield, N. J.

How to Repair Tractor Parts by Arc Welding. General Electric Company, Schenectady, N. Y., 7 pages.

Electro Rust Proofing System of Cathodic Protection. Electro Rust-Proofing Corporation, Dayton 10, Ohio.

Motors and Control for Hazardous Locations. General Electric Company, Schenectady, N. Y., 26 pages.

Putting Electricity to Work on Your Farm. Westinghouse Electric Corporation, East Pittsburgh, Pa., 52 pages. Five cents.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

A 208Y/120-Volt 120-Ampere Three-Pole 400-Cycle Electrically Operated Aircraft Circuit Breaker

C. H. TITUS
ASSOCIATE AIEE

P. J. REIFSCHNEIDER
ASSOCIATE AIEE

Synopsis: With the selection of the 208Y/120-volt three-phase 400-cycle a-c system by the Army Air Forces for large aircraft, there has arisen the need for appropriate switchgear. In order to be applicable to the electric systems of such planes, switchgear must be able to perform its normal and emergency functions under the encountered conditions of temperature, pressure, humidity, vibration, and acceleration. This paper describes a 120-ampere remotely controlled electrically operated air circuit breaker designed for use as a bus sectionalizing, ring tie, or generator breaker on the 400-cycle grounded-neutral system. The interrupting rating of this breaker is 3,800 amperes at all pressures from sea level to 50,000 feet altitude. The closing solenoid and shunt trip coils have been designed to operate over a wide range of ambient temperature and control voltage. Weight and size, being primary considerations in aircraft equipment, have been held to a minimum.

TO MEET the demands of increased electric loads in aircraft, the Army Air Forces has selected the 208Y/120-volt three-phase 400-cycle grounded-neutral a-c system as applicable to large aircraft.[1] Supplementing this system will be found a 24-volt d-c source for control power and some small loads. There are many reasons why an a-c system of this voltage and frequency has been selected for large aircraft. However, it is beyond the scope of this paper to treat them. A complete study of the factors entering into the selection of electric systems for aircraft has been presented in another paper.[2]

Heretofore, only small amounts of 400-cycle power, by comparison, have been used on aircraft. Equipment for the generation, distribution, and utilization of large amounts of 400-cycle power has been recently developed or may be still undergoing development. The weight and size of this equipment, it is specified, must be held to a minimum. Circuit breakers must be able to perform their normal and emergency functions under these conditions:

1. Altitude—from sea level to 50,000 feet, or a pressure range of from 14.7 to 1.68 pounds per square inch.

2. Temperature — ambient - temperature range from 60 to −70 degrees centigrade at sea level and from −40 to −65 degrees centigrade at 50,000 feet altitude.

3. Humidity—a relative humidity of from 0.5 to 100 per cent.

4. Vibration and acceleration—an amplitude of 0.030 inch at all frequencies from 10 to 50 cycles per second.

An air circuit breaker, custom built for aircraft to operate under these conditions, has been developed for the 400-cycle system. Figure 1 shows several views of this breaker designed for use as a bus sectionalizing, ring tie, or generator breaker. The weight of this breaker is five pounds and the over-all size is $7^1/_4$ inches high, $4^1/_8$ inches wide, and $4^{17}/_{32}$ inches deep. All parts are enclosed within a dust-resisting molded phenolic case on the back of which are the line, load, auxiliary-switch, and control-circuit terminals. The breaker may be mounted with these terminals either toward or away from the panel. In either position, the terminals are covered with insulating barriers.

Throughout the breaker, parts have been plated in accordance with accepted aircraft standards to prevent corrosion. Precautions have been taken to prevent moisture absorption and fungus growth by applying protective finishes to nonmetallic parts.

In the development of a circuit breaker, it is the requirements of the interrupter in terms of pressure, wipe, separation, and acceleration of the contact tips which determine the design of the operating mechanism and in turn the design of any closing and tripping devices. The interrupter, therefore, will be described first.

The Interrupter

It is required that the interrupter and contacts of this breaker be able to do the following:

1. Withstand vibration and acceleration as specified without physical damage or excessive heating.

2. Close and interrupt maximum available short-circuit current in the 208Y/120-volt three-phase grounded-neutral 400-cycle system at any altitude from sea level to 50,000 feet.

3. Carry 120 amperes continuously, 165 amperes for five minutes, and 245 amperes for five seconds without excessive temperature rise.

Before the interrupter and contact structure for a circuit breaker can be designed there are two dependent variables to be evaluated, namely, the type of contact material and the arc-quencher construction to be used.

Table I. Data for Representative Three-Phase Interrupting Tests Made at 230Y/133 Volts, 420 Cycles

Breaker Current, Rms Amperes	Maximum Arc Duration in Milliseconds at Pressures Equivalent to the Indicated Altitudes		
	1,000 Ft	20,000 Ft	50,000 Ft
80	3.7	2.5	1.2
120	2.5	1.2	1.2
250	3.7	2.5	1.2
310	5.0	2.5	3.7
750	2.5	2.5	2.5
1,700	2.5	2.5	2.5
2,800	3.7	3.7	3.7
3,800	5.2	5.0	5.0

Contact Material

The contact material has a direct bearing on arc duration and the operating temperature, welding current, and deterioration of the contacts. The influence of the contact material on arc duration is determined by:

1. Melting temperature of contact material.

2. Ionization potentials of the metal vapors derived from contact-material decomposition.

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C. H. Titus and P. J. Reifschneider are with the General Electric Company, Philadelphia, Pa.

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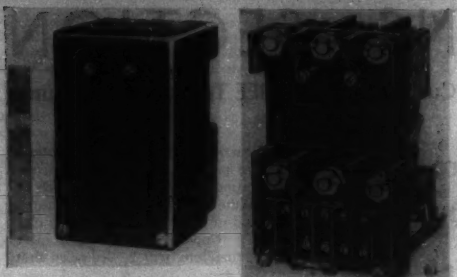
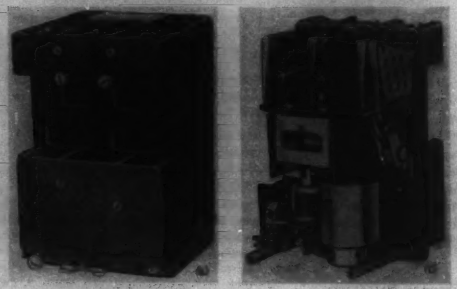


A—Front right view

C—Rear left view without covers showing load, line, and control-circuit terminals



B—Rear left view

D—Front right view without covers

Figure 1. A 208Y/120-volt 120-ampere three-pole 400-cycle electrically operated aircraft circuit breaker

3. Instantaneous temperature of contacts at time of parting.

The following factors determine the contact operating temperature:

1. Operating temperature of the member to which the contact itself is attached.

2. Resistivity of the contact material.

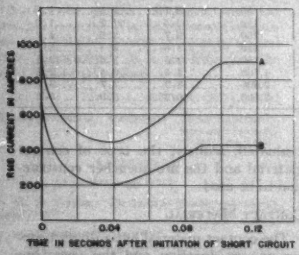


Figure 2. Short-circuit characteristics of 40-kva 208Y/120-volt three-phase 400-cycle aircraft alternator

Curves represent envelope of 400-cycle symmetrical current. First peaks may be increased because of offset. Voltage regulator operating in exciter field

A—Line-to-ground short circuit
B—Three-phase short circuit

3. Resistance of the point of contact of the movable and stationary members. This is a function of the contact pressure and the formation of chemical compounds on the surface of the contacts.

4. Composition and mass of material surrounding the contact structure. It is this material which determines the amount of heat energy removable from the contacts at any given operating temperature.

The instantaneous value of current at which a given set of contacts will weld is determined by:

1. Physical properties of contact material, namely, composition, melting temperature, thermal conductivity, and hardness.

2. Contact temperature, that is the transient temperature attained for any given value of current.

3. The instantaneous pressure present for any given operating current.

The following determine the deterioration of the contacts when interrupting both normal and short-circuit currents:

1. Magnitudes of the arc current.

2. Arc duration.

3. Melting temperature of contact material.

4. Hardness of the contact material.

5. Presence of gas-producing substances included in contact composition.

In order to determine the type of contact material which best meets the requirements of low operating temperature, high welding current, short arc duration, and minimum contact deterioration, approximately 1,100 tests were made using 14 types of contact material. These tests were made at ten per cent above the rated voltage and at pressures equivalent to altitudes ranging from 1,000 to 50,000 feet using 16 different types of arc quenchers. The type of contact material selected as best fulfilling these requirements is a sintered mixture of silver and tungsten.

Arc-Quencher Design

The design of the arc quencher has a direct bearing upon the magnitude of voltage and current which can be successfully interrupted, the arc duration for any combination of voltage and current, and the atmospheric conditions of humidity, temperature, and pressure under which the interrupter will function satisfactorily. The type of mechanism needed to operate the contacts and the size and weight of the arc quencher are dependent upon its design.

Since the neutral of the 208Y/120-volt three-phase 400-cycle system is solidly grounded, it is unlikely that a sustained voltage of more than ten per cent in excess of 120 volts will appear across a given breaker pole. Consequently, 132 volts will be considered the rms operating voltage of each arc quencher.

The system is supplied by four 40-kva 0.75-power-factor 400-cycle alternators. The short-circuit characteristics of the alternator, exciter, and voltage regulator combined are shown in Figure 2. Inspection of Figures 2 and 3 shows that the maximum fault current results from a single-phase line-to-ground fault. From Figure 3, it is evident that with any possible location of such a fault, the maximum short-circuit current which a single pole of any breaker may be called upon to interrupt is that contributed by three generators and the connected motors. Studies of the proposed system,

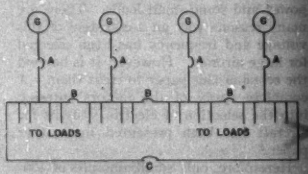


Figure 3. Proposed power circuit for 400-cycle aircraft system, using remotely controlled electrically operated circuit breakers

G—208Y/120-volt 40-kva 0.75-power-factor 400-cycle alternator
A—Generator breaker
B—Bus-sectionalizing breaker
C—Ring-tie breaker

which take into account circuit impedances, indicate that the interrupting rating of the breaker, 3,800 amperes, will not be exceeded.

A test circuit was set up as shown in Figure 4 for determining, at first, the best type of arc quencher, and later, the overall performance of the complete breaker under single-phase and three-phase fault conditions. Test currents ranging from 3 amperes to 4,000 amperes for both single- and three-phase operation were obtainable on a 230Y/133-volt 420-cycle system with a system power factor of approximately 15 per cent. All interrupting tests were made in a chamber capable of being evacuated to an equivalent pressure less than that encountered at 50,000 feet altitude.

Because the arcing time of most conventional 120-volt air circuit breakers increases materially at the decreased atmospheric pressures encountered at high altitude, it seemed necessary at first to use a compression-type interrupter. An interrupter of this type is capable of generating its own internal pressure. However, interrupting tests indicated that over the operating range of currents and pressures of this breaker, a converging-slot-type arc quencher performs as well as the compression-type interrupter. The advantages of the lightweight, mechanically simple, converging-slot-type arc quencher over the heavier, more complex, compression-type interrupter made it ideally suited to this type of aircraft application.

Two views of this converging-slot-type arc quencher with the lower portion of one side removed are shown in Figure 5. A front right view of the breaker is shown in Figure 6 with the cover, one phase barrier, and half of the right-pole arc quencher removed. The movable and stationary contact members together with the magnet frame are so arranged that the arc stream and its terminals are driven toward the top of the breaker as it is shown in Figure 6. The contour of the inside of the arc quencher has been made such that unnecessary extension of the arc is avoided to obtain a maximum amount of cooling in a minimum amount of time. The deterioration of the arc quencher and the contacts is thereby minimized during interruption.

Table I is a tabulation of data of representative three-phase interrupting tests made at 230Y/133 volts, 420 cycles, and pressures equivalent to altitudes from 1,000 to 50,000 feet. The maximum arc duration in milliseconds is shown for various currents and altitudes. Oscillograms showing typical breaker operation when interrupting three-phase 420-cycle short-circuit currents of approximately 2,900 amperes and 3,600 amperes at corresponding pressures equivalent to 50,000 feet and 20,000 feet altitude are shown in Figures 7 and 8. Continuous-current-carrying tests made at 120 amperes and short-time overload tests made at 165 amperes and 245 amperes indicate that the thermal capacity of the breaker is adequate for use on this system.

Operating Mechanism

A latching-type solenoid-operated toggle mechanism is used to close the hinged contacts against a heavy opening spring. The contacts are opened by energizing the shunt trip coil, the plunger of which releases the latch and permits the opening spring to pull the contacts rapidly to the open position. It is necessary that the contacts be parted as quickly as possible to minimize the over-all interrupting time.

No means have been provided for closing or opening the breaker manually, nor have any overload tripping devices been incorporated in the breaker.

In Figure 9 is shown the relative size of the subassembly of the shunt trip device and the closing solenoid. Because of the design of these two devices and the fact that the coils have only a short-time rating, the work output per unit of weight is high for both of them. The ratio of the

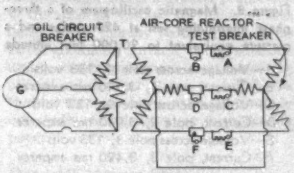


Figure 4. Test circuit used for interrupting tests

Letters *A*–*F* indicate magnetic oscillograph vibrators:

A—Voltage across pole 1
B—Current, pole 1
C—Voltage across pole 2
D—Current, pole 2
E—Voltage across pole 3
F—Current, pole 3
G—Alternator, 3,000 kva, 2,400 volts, three phase, 420 cycles
T—Transformer, 600 kva, 2,400 delta–208Y volts (60-cycle rating)

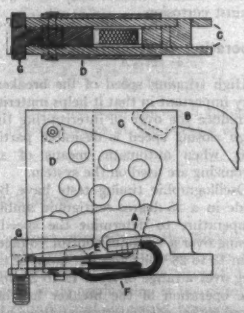


Figure 5. Top and side views of converging-slot-type arc quencher for 208Y/120-volt 120-ampere three-pole 400-cycle aircraft circuit breaker

Lower portion of one side removed

A—Stationary contact
B—Movable contact
C—Arc chute
D—Magnet frame
E—Leaf spring
F—Flexible braid
G—Shield

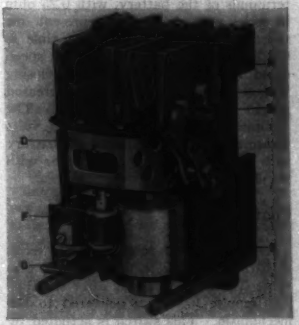


Figure 6. Front right view of breaker

One phase barrier and half of right-pole arc quencher removed showing the contact and arc-quencher construction

A—Arc quencher
B—Movable contact
C—Stationary contact
D—Mechanism
E—Closing solenoid
F—Shunt trip
G—Cutoff switch for closing solenoid

Figure 7. Magnetic oscillogram of a three-phase interrupting test at 420 cycles and a pressure equivalent to 50,000 feet altitude

A—Voltage across pole 1, 133 volts
B—Current, pole 1, 2,860 rms amperes
C—Voltage across pole 2, 133 volts
D—Current, pole 2, 3,230 rms amperes
E—Voltage across pole 3, 133 volts
F—Current, pole 3, 2,750 rms amperes

product of the force at the beginning of the stroke and the length of the stroke to the weight is 3.1 inch-pounds per pound for the closing solenoid and 3.3 inch-pounds per pound for the shunt trip device. This same ratio for a continuously rated commercial solenoid is 0.34 inch-pounds per pound. Weighing only 19 ounces, the closing solenoid develops more than 45 pounds at the point near the end of its stroke where the overtravel of the plunger begins. The shunt trip device weighs four ounces.

The pull curve of the closing solenoid has been so shaped that even at as low a voltage as 18 volts, measured at the terminals of the battery, with 0.25 ohm in series with the coil to represent line resistance, the breaker closing time is 0.027 second. Higher closing speed could be obtained at the expense of increased weight of the closing solenoid. The minimum tripping voltage is 12 volts measured at the terminals of the battery with 0.25 ohm resistance in series with the shunt trip coil.

Control Circuit

A cutoff switch connected in series with the coil of the closing solenoid prevents it from overheating after the closing impulse has been delivered to the mechanism. This switch is actuated by the solenoid plunger in the overtravel portion of its stroke after the mechanism has been fully closed. As long as the closing circuit is energized after the breaker has been closed, the cutoff switch, shown in Figure 10, is maintained in the open position by a holding coil. As this holding coil is continuously rated, it is possible to use either a momentary- or a maintaining-contact switch to control the closing of the breaker. When using the latter type of switch, the closing circuit must be de-energized after tripping and before reclosing the breaker. With this control scheme, it is impossible for the breaker to pump should it be closed against a fault with the closing circuit energized.

Included as an integral part of the breaker is a four-stage auxiliary switch. Each stage or set of contacts of this switch is a small snap-action vibration-proof contact mechanism. One stage is used as the auxiliary contact in series with the shunt trip to open its coil circuit the instant the breaker primary contacts open. The other three sets of contacts may be arranged individually to be either normally open or normally closed and used with external relays for breaker control. The terminals of these contacts are brought out to the back of the breaker with the close, trip, and ground terminals as shown in Figure 1C.

The three control-circuit coils have a tropical treatment. Polyvinyl-chloride-insulated wire is used for all internal control-circuit connections to guard against corrosion.

Figure 8. Magnetic oscillogram of a three-phase interrupting test at 420 cycles and a pressure equivalent to 20,000 feet altitude

A—Voltage across pole 1, 133 volts
B—Current, pole 1, 3,510 rms amperes
C—Voltage across pole 2, 133 volts
D—Current, pole 2, 3,940 rms amperes
E—Voltage across pole 3, 133 volts
F—Current, pole 3, 3,420 rms amperes

Figure 9. Shunt-trip and closing-solenoid subassembly

Operating Characteristics

High tripping speed of the breaker is very important in that it helps materially to reduce the over-all interrupting time. High closing speed is desirable particularly when automatic means of synchronizing are used on the system.

Oscillographic timing tests have been made in a 25-degree-centigrade ambient temperature to determine the speed of closing over a range of control voltage of from 18 to 28 volts and the speed of tripping over a range of from 12 to 28 volts. The operation of the breaker has been found to be satisfactory over these same voltage ranges while being subjected to vibration with an amplitude of 0.030 inch at all frequencies from 10 to 50 cycles per second. For all operation tests, both closing and tripping, a 0.25-ohm resistor was connected in series with the ground terminal of the breaker control circuit to simulate line resistance in the plane.

Although the resistance of the coils increases somewhat when the breaker is placed in an ambient temperature of 60 degrees centigrade, the breaker closes satisfactorily at 18 volts and trips at 12 volts, both voltages being the open-circuit control voltage.

The closing characteristics, time from the instant the closing circuit is energized until the breaker primary contacts meet versus the open-circuit control voltage,

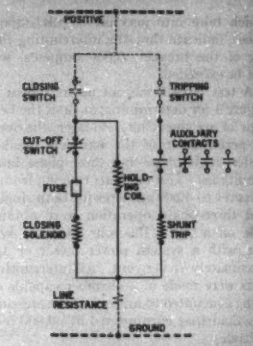


Figure 10. Control-circuit diagram, 208Y/120-volt 120-ampere three-pole 400-cycle electrically operated aircraft circuit breaker

Nominal d-c control voltage 24 volts

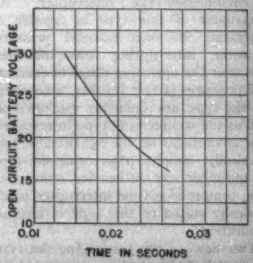


Figure 11. Closing characteristic, 208Y/120-volt 120-ampere three-pole 400-cycle electrically operated aircraft circuit breaker

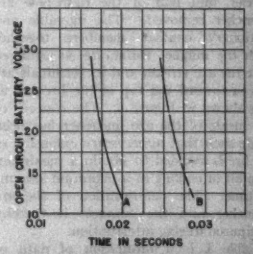


Figure 12. Opening characteristics, 208Y/120-volt 120-ampere three-pole 400-cycle electrically operated aircraft circuit breaker

A—Breaker primary contacts part
B—Breaker primary contacts fully open

Oil Stresses in Impregnated-Paper Insulation

J. B. WHITEHEAD
FELLOW AIEE

RECENT EXPERIMENT on fully impregnated cable-type paper insulation, has shown that under certain conditions use of a paper of low density results in a higher dielectric strength than does the use of a paper of higher density.[1] It has also been shown that failure of such insulation usually begins in the oil channels between successive turns of paper tape.

The former result is in apparent conflict with general experience that the denser a given substance or medium, the higher the dielectric strength. But the conflict is apparent only, for impregnated paper is not a homogeneous substance, and failure begins first in its weaker constituent, namely, the oil. High-density paper with its higher dielectric constant throws a higher stress into the oil channels and the critical or breakdown stress is reached at a lower applied voltage than when low-density paper of lower dielectric constant is used.

The following approximate analysis indicates that under certain conditions in a single-conductor cable of circular cross section, the use of high-density paper next the conductor and low-density paper outside should result in a higher over-all dielectric strength than that of the same cable insulated throughout with either low- or high-density paper. The higher specific inductive capacity of the high-density paper shifts a greater proportion of the over-all voltage to the outer less dense paper thereby reducing the stress at the conductor surface. This reduction under certain conditions may cause the critical oil-channel stress to fall below that for the same cable insulated throughout with low-density or high-density paper.

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Over-All Average Stress at Conductor Surface

Let a, b, and c be the radii of the conductor and of the outer surfaces of the denser and less dense papers respectively; K_{ab} and K_{bc} the measured dielectric constants of the two impregnated papers when assembled separately as cable insulation, and V_{ab} and V_{bc} the division of the total voltage, V_o, between them. Then we have:

$$V_{ab}+V_{bc}=V_o \tag{1}$$

$$\frac{V_{ab}}{V_{bc}}=\frac{K_{bc}}{K_{ab}}\cdot\frac{\log\,(b/a)}{\log\,(c/b)} \tag{2}$$

$$V_{ab}=\frac{K_{bc}}{K_{ab}}\cdot\frac{\log\,(b/a)}{\log\,(c/b)}\,(V_o-V_{ab}) \tag{3}$$

$$=\frac{A}{1+A}\cdot V_o;\quad A\equiv\frac{K_{bc}\log\,(b/a)}{K_{ab}\log\,(c/b)} \tag{4}$$

Also, let E_a and E_b be the mean values of the radial stresses at the surface of the conductor, and at the outer surface of the inner denser paper respectively; then we have

$$\left.\begin{aligned}E_a&=\frac{V_{ab}}{a\,\log\,(b/a)}\\ E_b&=\frac{V_{bc}}{b\,\log\,(c/b)}\end{aligned}\right\} \tag{5}$$

and from equation 2

$$\frac{E_a}{E_b}=\frac{V_{ab}}{V_{bc}}\cdot\frac{b\,\log\,(c/b)}{a\,\log\,(b/a)} \tag{6}$$

$$=\frac{K_{bc}}{K_{ab}}\cdot\frac{b}{a} \tag{7}$$

Also

$$E_a=\frac{V_o\cdot A}{(1+A)a\,\log\,(b/a)}$$

$$E_a=\frac{V_o}{a\left[\dfrac{K_{ab}}{K_{bc}}\cdot\log\,(c/b)+\log\,(b/a)\right]} \tag{8}$$

In equation 8 E_a is a mean or average value of the electric stress at the conductor surface. Its value is readily determined from measured values of V_o and of the dimensions a, b, and c, and of the specific inductive capacity of each of the papers when assembled separately as cable-type insulation. For an insight as to how the value of E_a varies as the proportion of dense to lighter papers varies, we may consider two papers each five mils thick; paper A (specific gravity 0.74; K = 3.78) and paper D (specific gravity 1.18; K = 4.91). Also in order to limit the number of variables, let us consider the particular case in which the total thickness of insulation is equal to the diameter $2a$ of the central conductor: thus $c = 3a$; in Figure 1 the curve E_a shows how E_a varies for all values of b. We note that for $b = a$ (all A paper) and for $b = 3a$ (all D paper), the values of E_a are the same and at their greatest. Introduction of any small amount of D paper inside of

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are shown graphically in Figure 11. At the nominal control voltage, 24 volts, the closing time is 0.02 second.

The opening characteristics, time from the instant the shunt trip is energized until the breaker primary contacts part and until they are fully open versus the open-circuit control voltage, are shown in Figure 12. The time from the parting of the contacts until they reach the fully open position, 8.5 milliseconds, is independent of the control voltage. The arcing time at pressures equivalent to altitudes up to 50,000 feet and currents up to 3,800 amperes rms, from Table I, never exceeds 6.2 milliseconds. The right-hand curve of Figure 12, contacts fully open, shows the interrupting time of the breaker versus control voltage at 50,000 feet altitude and rated interrupting current.

Conclusions

Designed primarily for the 208Y/120-volt 400-cycle a-c system selected by the Army Air Forces for large aircraft, this breaker in its application is the counterpart of industrial air circuit breakers.

The outstanding features of this breaker are:

1. Satisfactory and reliable operation under extreme conditions of temperature, pressure, humidity, vibration, and acceleration normal to aircraft.

2. Adequate interrupting capacity for the proposed 400-cycle aircraft system.

3. Short closing and tripping times over a wide range of control voltage.

4. Light weight and small space requirements.

5. Protection of parts against fungus growth and corrosion.

Future increases in aircraft electric loads will undoubtedly call for more extensive systems using breakers of higher continuous and short-circuit ratings. The experience gained in the design of this breaker indicates that these demands can be met without sacrificing any of the present features.

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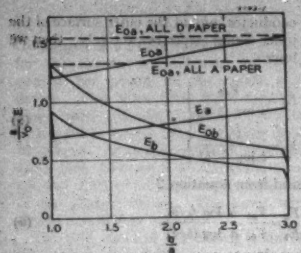

Figure 1. Stresses in a graded cable, denser paper inside, range of b/a from 1 to 3

Paper *D*, inside, specific gravity 1.18
Paper *A*, outside, specific gravity 0.74
25 per cent overlay, $n = 4$
E_a—Average stress at conductor surface
E_{oa}—Stress in oil channel of paper *D* at conductor surface
E_{ob}—Stress in oil channel of inside layer of paper *A*
E_b—Average stress at surface of separation of the two papers

A paper, that is, for values of b slightly above a, E_a is sharply reduced and then increases approximately linearly to its maximum at $b = c = 3a$.

Similarly, the average stress at the surface of separation of the two papers (equation 7) is plotted as curve E_b. Its maximum value occurs at $b = a$ (all *A* paper) and is the same as the maximum value of E_a.

Figure 2 shows similar variations of the several stresses for values of b/a of from 1 to 2, that is for insulation wall thickness equal to the radius of the conductor.

Stress in Oil Channels

So far E_a and E_b are independent of the thickness and overlay of the paper tapes, except as these affect the measured values of K_{ab} and K_{bc}.

But we have taken the stress in an oil channel at the conductor as a measure of dielectric strength, and so it remains to determine the value of this stress, E_{oa}, in terms of some measurable quantity, for example, E_a. Efforts to derive the completely accurate value for E_{oa} lead to difficult and cumbersome expressions. We can proceed however, much more easily and with perhaps equal accuracy if we make two assumptions:

(a). That the pattern of overlay of tapes repeats itself regularly through the insulation wall.

(b). That the electric stress in the central region of the oil channel and immediately overlaying paper tapes is radial and uniform.

Under the first assumption the insulation wall may be considered as made up of a number of coaxial cylindrical capacitors, each having the same radial thickness, the same number of paper layers, the same overlay of tapes, and the same width of oil channel; also, for any one type of paper the dielectric of each elementary capacitor will have the same value of specific inductive capacity; or in other words K_{ab} and K_{bc} in the respective papers would have the same value if measured over any one or more of the characteristic elementary capacitors.

Assumption *b* is warranted by the fact that the oil channel is usually from 10 to 20 times as wide as it is thick (0.005 inch). We fix our attention on the central part of the channel where the stress is very nearly uniform and at its maximum value.

With all dimensions of the single-conductor cable and the applied voltage given, these assumptions enable us to compute, to a close approximation the value of the voltage, V, across the innermost characteristic capacitor, and further to derive the value of the stress in the innermost critical oil channel in terms of the average surface stress E_a of equation 8, as follows:

The characteristic capacitor will have a number of layers, n, depending on the overlay, and any oil channel adjacent to the conductor will be in series radially with $n - 1$ paper tapes. Let us consider only that elementary portion of the innermost capacitor for which an oil channel is next to the surface of the conductor. Then, if we make the not too violent assumption that the stress in the central region of the channel is radial, we may

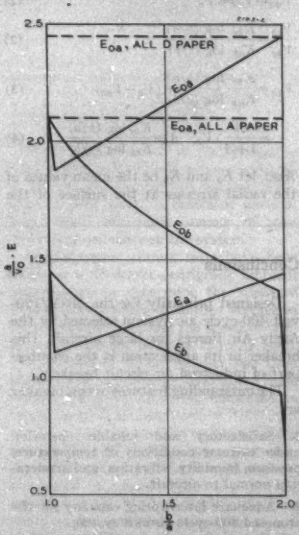

Figure 2. Stresses in a graded cable, denser paper inside, range of b/a from 1 to 2

See subcaption of Figure 1

compute the stress in the oil channel from the relations in a cylindrical capacitor with an inside layer of oil, and above it $n - 1$ layers of impregnated paper.

If a is the radius of the conductor, and $a_1, a_2 \ldots a_n$ the radii of the successive paper layers, and V is the voltage over the innermost capacitor, and K_o and K_p the dielectric constants of oil and impregnated papers respectively, then remembering the assumption *b* and formula 4, we find V_{oa}, the voltage over the oil channel,

$$V_{oa} = \frac{BV}{B+1}$$

where

$$B = \frac{K_p \log (a_1/a)}{K_o \log (a_n/a_1)} \tag{9}$$

and the stress E_{oa}, in the oil channel and at the surface of the conductor,

$$E_{oa} = \frac{V_{oa}}{a \log (a_1/a)} = \frac{V}{a\left[\log (a_1/a) + \frac{K_o}{K_p} \log (a_n/a_1)\right]} \tag{10}$$

Also since the innermost capacitor in each paper is typical of all:

$$E_a = \frac{V}{a \log (a_n/a)} = \frac{V}{a \log\left(\frac{a+nt}{a}\right)} \tag{11}$$

where t is the thickness of the paper tape.

Whence

$$E_{oa} = \frac{E_a \log\left(\frac{a+nt}{a}\right)}{\log (a_1/a) + \frac{K_o}{K_p} \log (a_n/a_1)} = GE_a \tag{12}$$

$$G = \frac{\log\left(\frac{a+nt}{a}\right)}{\log (a_1/a) + \frac{K_o}{K_p} \log (a_n/a_1)} \tag{13}$$

the stress in an oil channel at the surface of the conductor.

For a given conductor, paper, and overlay in assembly G is a constant; when two papers are used, G has two values, one for each paper as determined by the two values of K_p, the specific inductive capacity of the impregnated paper. The values of G will always be greater than the average stress E_a at the conductor surface, if as is commonly the case K_p is greater than K_o.

In Table I values of G are given for several values of a and n, within the range of cable practice, and for each of the papers *A* and *D*. As will be seen, the values of G are practically independent of the conductor radius within the range 0.125 inch to 0.500 inch but increase with increase in n, the numbers of layers of paper in the "characteristic capacitor" or pattern of assembly. The greatest

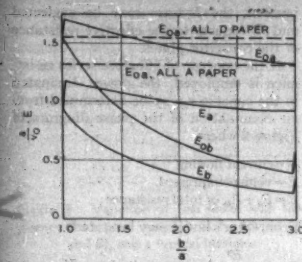

Figure 3. Stresses in a graded cable, denser paper outside, range of b/a from 1 to 3

Paper A inside, paper D outside; see subcaption of Figure 1

value of G, within the range examined, is 1.70, D paper with $n = 4$ (25 per cent overlay), and the smallest 1.26, A paper with $n = 2$ (50 per cent overlay). These then are the factors by which the values of E_a and E_b plotted in Figure 1 are to be multiplied to give the stresses in the oil channels of the innermost layers of the inside denser paper and the outside less dense paper respectively. The resulting curves E_{oa} and E_{ob} have been plotted in Figure 1; also, in horizontal dotted lines, for the purposes of comparison, the values of the stresses in the oil channels at the conductor surface when the insulation is entirely of D paper and of A paper respectively.

We note from Figure 1 that in the special case there considered ($n = 4$, $b/a = 1$ to 3), for $b/a = 1$ (all A paper) and for $b/a = 3$ (all D paper) the average stress E_a has the same value as is well understood. However, in both cases the maximum oil stress is higher than E_a—the average maximum stress, 1.7 times for the denser paper D and 1.46 times for the less dense paper A (see Table I); the resulting difference is indicated by the horizontal dotted lines at the top of the figure.

This confirms qualitatively, and in terms of simple physical principles, the experimental result found by the author that in cable-type fully impregnated paper insulation a denser paper has a lower dielectric strength than a less dense paper.

When both types of paper are used in the same insulation wall, and, as we have assumed, the denser paper is on the inside, we see at once that for values of b/a between 1 and 1.75 the maximum oil stress E_{oa} in the denser paper is lower than the maximum oil stress in the case when the entire wall consists of the less dense paper. Thus properly proportioned graded insulation may have a lower maximum oil stress and a higher dielectric strength than either of its constituents when used singly for the same wall thickness of insulation.

Table I. Values of G for papers of two values of density (D and A)

Radius of Conductor, a, Inch	$n=2$		$n=3$		$n=4$	
	D	A	D	A	D	A
0.125	1.37	1.26	1.65	1.37	1.68	1.45
0.25	1.37	1.26	1.66	1.37	1.70	1.46
0.375	1.40	1.29	1.62	1.41	1.67	1.43
0.500	1.38	1.28	1.61	1.37	1.70	1.45

The stress E_{ob} in the inside oil channels of the outer less dense paper is always less than that in the inside channels of either paper used alone. However, in the graded case we note from Figure 1 that for values of b/a between 1 and 1.12, E_{ob} rises above E_{oo}, that is to say, breakdown is more likely to occur in the inside layers of the outer less dense paper.

Figure 2 shows that similar relations with only small variations in values occur when the total insulation wall thickness is one-half the diameter of the conductor, that is, the range of b/a is from 1 to 2.

It is of interest to note the relations which arise when in the graded cable the positions of the two grades of paper are reversed, that is, when the low-density paper is placed on the inside, adjacent to the conductor. These relations are shown in Figure 3 for a variation of b/a from 1 to 3, and so may be compared with those of Figure 1. As seen, for all values of b/a, that is, for any radial depth of the less dense paper, the stress in the oil channels next to the conductor is higher than if the low-density paper were used alone; up to $b/a = 1.55$ the stress is higher than if the high-density paper were used alone. The higher dielectric constant of the outer high-density paper shifts such a large fraction of the total voltage to the low-density paper that the lower oil–paper stress ratio of the latter is surpassed over the entire range.

The methods used in the foregoing analysis are approximate at several points, and several conditions obtaining in cable insulation as manufactured have not been introduced, as for example the stranding of the central conductor, the spiral course of the oil channels, and space-charge action in the oil channels. It is believed, however, that the bearing of these elements will be much the same relatively in each of the several cases compared, and that their influence would appear only in a possible attempt at a quantitative derivation of stress values.

The experiments referred to in the opening paragraph were conducted at 60 cycles, on thoroughly impregnated insulation in which there was at no time any evidence of internal gas pockets. Discussion has suggested, therefore, that the clear evidence of a higher dielectric strength of a lower density over a higher density paper should be restricted to thoroughly impregnated insulation of the oil-filled or other similar type, and not be extended to so called solid-type insulation, in which it is generally admitted that following load cycles, or due to other cause, gas pockets or layers are present, and that the range of breakdown stress values is substantially lower than those encountered in the author's tests. It is also suggested that a different result might be found even in insulation of the oil-filled type in breakdown tests of impulse type.

Some comment on this type of discussion will be found in the paper by Whitehead and Kopper.[1] It is not, however, within the purpose of this paper to continue that discussion, but rather to show in terms of simple physical principles and of the experiments referred to, that the use of high-density paper in cable insulation should result in a higher dielectric strength if used in combination with lower density paper in suitably proportioned graded insulation, than would result in the use of either grade of paper alone.

It is also fair to emphasize that the principles utilized herein, depending as they do only on variations of dielectric constant, must apply to all types of cable insulation, oil-filled, solid, gas-filled, or other, insofar as the values and distribution of dielectric stress are concerned. Whether or not complete breakdown is a function of maximum dielectric stress only, is another question, discussion of which also falls outside the scope of this paper.

The results of this study are offered as a possible explanation of the recent conflict of opinion as to the influence of high-density paper in cable insulation.

Conclusions

1. In cable-type impregnated-paper insulation the use of all high-density paper results in a higher maximum stress in the oil channels than does a low-density paper.

2. The use of both high- and low-density paper, with the former inside, as in a graded cable, may result in a lower maximum oil stress, and so a higher dielectric strength, than if all low-density paper or all high-density paper is used.

Reference

1. THE DIELECTRIC STRENGTH AND LIFE OF IMPREGNATED PAPER—IV, J. B. Whitehead, J. M. Kopper. AIEE TRANSACTIONS, volume 64, 1945, April section, pages 171–7.

The Role of Frequency in Industrial Dielectric Heating

G. W. SCOTT, JR.
MEMBER AIEE

A TENDENCY has developed to look upon frequency as a variable in dielectric heating which may be increased at will in order to increase the rate of heating quite independently of other factors. No doubt this tendency has been fostered by the acceptance without knowledge of its derivation of the equation for rate of dissipation of high-frequency energy in a dielectric, wherein the frequency term appears to the first power and in the numerator. The purpose of this paper is to analyze more carefully the role of frequency in industrial dielectric heating. The expression for the rate of heating will be critically examined, particularly with reference to the direct influence of frequency and its indirect influence through certain of the other variables of the heating equation that are not independent of frequency. In the light of this and other known effects of frequency, an attempt will be made to determine the practical upper limit of frequency for large-scale industrial dielectric-heating installations. It is hoped that, as a result of this discussion, there will result in the future a more precise use of the term frequency as related to dielectric heating. It should be pointed out that, in order to express the effect of frequency quantitatively, it has been necessary either to assume the ideal condition of pure L and C or to assume reasonable values of capacitance to ground and of distributed L and C. For this reason it has been possible in certain instances only to establish limits.

It is apparent from the analysis to follow that:

1. None of the variables in the heating equation is completely independent of frequency or its effects.
2. As frequency is increased, load capacitance must be decreased to allow tuning and to avoid short-circuiting the generator.
3. At higher frequencies load length must be kept at a minimum to eliminate the possibility of standing waves.
4. Increased frequency accentuates the load-shunting effect of stray capacitance and seriously reduces the over-all efficiency of the dielectric heating.

Therefore, it appears likely that the frequency band from 10 to 30 megacycles will prove best adapted for large-scale industrial dielectric heating, that is for load capacitances up to 500 micromicrofarads and for output power as high as 100 kw.

Equations for Development of Dielectric Heat

An expression for the heat developed in a dielectric by the application of an alternating voltage may be derived readily from the theory of the imperfect capacitor, represented schematically in Figure 1. Whenever there is an imperfectly insulating material to be heated between the plates of a capacitor, the

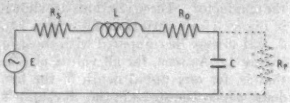

Figure 1. Equivalent circuit of dielectric heating load

E—Oscillator
C—Capacitance
R_s—Effective series resistance
R_p—Effective parallel resistance
L—Residual inductance
R_0—Residual resistance

latter may be considered as a capacitance with either a resistance R_s in series or a resistance R_p in parallel. These resistances are defined as

$$R_s = \frac{\cos\theta}{\omega C} \tag{1}$$

$$R_p = \frac{1}{\omega C \cos\theta} \tag{2}$$

where

$\cos\theta$ = power factor of material heated and $\cos\theta \leq 0.1 = \sin\delta = \tan\delta$
C = capacitance of load
$\omega = 2\pi$ (frequency)
E = alternating voltage

In addition there is associated with the capacitor a certain residual inductance L and resistance R_0. As, for simplicity in this analysis, the effect of leads will be ignored, the L term may be neglected and R_0 reduces to the effective resistance of the capacitor plates.

If the concept of effective series resistance is employed, the power dissipated in the capacitor may be determined from an examination of the phase diagram of Figure 2 where

I = current flowing
E = voltage impressed
$R = R_s + R_0$, or total resistance

From Ohm's law it may be stated:

$$\text{Power} = \frac{E^2}{R} = \text{heat per unit time} = H$$

Therefore, the heat developed in the resistance R may be expressed:

$$H_R = \frac{E_R^2}{R} = \frac{E^2\cos^2\theta}{\dfrac{1}{\omega C \tan\theta}} = \omega C E^2 \cos\theta \sin\theta \tag{3}$$

where

$$\theta = \tan^{-1}\left(\frac{1}{\omega C R}\right)$$

$\cos\theta$ = power factor of capacitor

Equation 3 is the general equation governing the development of heat in an imperfect capacitor. If desired, $\sin\theta$ may be replaced by $\sqrt{1-\cos^2\theta}$.

If the effective resistance of the capacitor plates may be neglected, an expression for the purely dielectric heat developed within the plates may be derived as follows:

$$H = \frac{E_R^2}{R_s} = \frac{E^2\cos^2\theta}{\dfrac{\cos\theta}{\omega C}} = \omega C E^2 \cos\theta \tag{4}$$

where

$\cos\theta$ = power factor of material heated (≤ 0.1)

Equation 4 may be verified by considering the effective parallel resistance R_p as the dissipative element.

For plane parallel electrodes and negligible effective resistance equation 3 takes the form:

$$W = \frac{5}{9} k \cos\theta f \left(\frac{E}{d}\right)^2 \times 10^{-12} \tag{5}$$

where

W = heat in watts per cubic centimeter
k = dielectric constant of material heated
$\cos\theta$ = power factor of material heated (≤ 0.1)

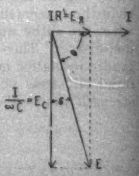

Figure 2. Phase diagram for dielectric-heating load

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Credit is due to I. J. Barney for assistance in certain of the calculations and to G. B. Gard and K. D. Lawson for advice on the practical aspects of frequency in dielectric heating.

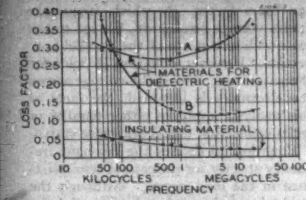

Figure 3. Variation of loss factor with frequency for typical materials to be heated (*A* and *B*), and a typical insulator

f = frequency in cycles per second

$\frac{E}{d}$ = voltage gradient in volts per centimeter

Equation 3 may be evaluated for any electrode configuration whose capacitance may be expressed although the heating will be uniform only in those instances where the electric field is uniform.

Examination of equations 4 and 5 shows that the magnitude of the heat generated is determined collectively by

(*a*). The geometry of the load.

(*b*). Its electrical properties.

(*c*). The characteristics of the source of high-frequency power.

The appearance of C in equation 4 clearly establishes the dependency of the heating upon load geometry. Equation 5 for plane parallel electrodes, perhaps the most frequent situation in industrial dielectric heating, includes dielectric constant and power factor which are, of course, inherent electrical properties of the material being heated. Furthermore, both equations contain frequency and voltage terms, which are determined not altogether independently by the oscillator and the coupling to the load circuit.

From a cursory analysis of equation 5, it is reasoned that increased frequency will allow somewhat decreased voltage to accomplish equivalent heating or linearly decreased time of heating if the voltage is maintained constant. As a result considerable emphasis has been placed on higher frequency for industrial dielectric heating to gain these advantages. This emphasis in many instances, has been misplaced since

1. The acquirement of greater skill has allowed high-frequency voltages up to 25 kv to be insulated.

2. The remaining terms in the heat equation are not independent of frequency.

3. Increased frequency causes serious limitations in itself.

Variables in Heat Equation not Independent of Frequency

In equations 3, 4, and 5 no terms are independent of frequency except the numerical constants, although certain quantities are more directly a function of frequency than others. Both dielectric constant, k, and power factor, $\cos\theta$, are direct functions of frequency and incidentally of temperature as well. The product of these two quantities is known as the loss factor of the material in question, and it has been plotted versus frequency in Figure 3 for two materials suitable for industrial dielectric heating, A and B, and for one material suitable as a high-frequency insulator. Although attention has been called by some to frequencies at which maxima and minima occur in the loss-factor curve, this fact is not of great value in shortening heating cycles because, even in approaching such points, a given percentage change in frequency normally results in a much smaller percentage change in loss factor. In general, it may be said that relatively good high-frequency insulators exhibit a loss-factor characteristic that slowly diminishes as frequency increases, whereas materials suitable for high-frequency heating may either increase, decrease, or go through maxima and minima as frequency increases. Although variations of loss factor in a given material seldom warrant choice of a particular frequency to increase the heating rate, large variations between different materials may require higher frequencies to heat the better insulators.

When a parallel resonant circuit containing an imperfect capacitor, as is the case in a dielectric-heating load circuit, is tuned to resonance, it presents to the oscillator an approximate resistive impedance:

$$Z_R = 10^6/(2\pi f C \cos\theta) \text{ ohms} \qquad (6)$$

where

f = frequency in megacycles

C = capacitance in micromicrofarads between electrodes

$\cos\theta$ = power factor of dielectric

This is true because at resonance the parallel circuit offers infinite impedance, but shunted with the effective parallel resistance of the dielectric, R_p. Consequently, the impedance, Z_R, in equation 6 is merely R_p, since the latter is much less than infinity for conditions that allow the development of appreciable dielectric heat.

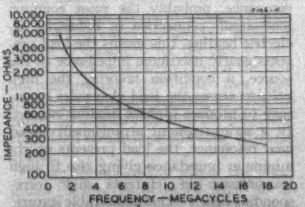

Figure 4. Variation with frequency of impedance for a dielectric-heating load (material *A*, Figure 3) tuned to parallel resonance

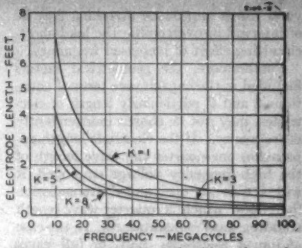

Figure 5. Maximum tolerable electrode length allowing ten-per-cent voltage variation as a function of frequency

K = dielectric constant

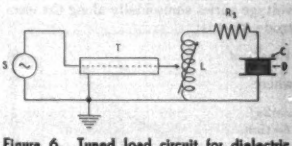

Figure 6. Tuned load circuit for dielectric heating

S—Oscillator
T—Coaxial transmission line
L—Tuning inductance
R_s—Effective series resistance
C—Electrodes
D—Material to be heated

In Figure 4 Z_R has been plotted as a function of frequency for a 36-by-36-by-3-inch (100-pound) load of material, *A*, presented in Figure 3. For this load the capacitance varies from 388 to 330 micromicrofarads over the frequency range considered. The impedance across the load is seen to diminish markedly with frequency.

The power transfer to and voltage drop across a load necessary for heating depend upon the impedance match between the output of the oscillator and the load circuit. As an increase in frequency will reduce load impedance, a reduced voltage will exist across the load, thereby minimizing power transfer, other factors remaining the same and the load capacitance having been tuned to the new frequency. Consequently, voltage may not be maintained constant across a load to shorten a heating cycle as frequency is increased unless adjustments are made to maintain the impedance match. If the oscillator is assumed to have an output impedance of 300 ohms and the load to be tuned with a high Q parallel resonant circuit, Figure 4 shows that the impedances would be matched for the load in question at 15.5 megacycles if the terminals of the oscillator were connected directly across the load. At much higher frequencies some sort of impedance-matching network would be required. There are, of course, practical limits be-

yond which impedance matching may be of no avail in overcoming the load short-circuiting effect of increased frequency.

Furthermore, the geometrical factors included in the capacitance term of equations 3 and 4, particularly length of electrodes, may not be chosen independently of frequency. If the electrode length approaches one-quarter the wave length of the high-frequency voltage employed, it will act as an open-ended transmission line upon which a quarter-wave-length standing wave is maintained. In the case of longer electrodes, half- or full-wave-length standing waves may exist or any multiples thereof. This, of course, will result in nonuniform generation of dielectric heat.

In the case of such a standing wave the voltage varies sinusoidally along the electrode, that is:

$$V = \sin \omega t \tag{8}$$

where

$\omega = 2\pi f$
t = time

For an electrode the voltage at any point may be expressed:

$$V = V_{max} \cos 2\pi f t$$

where

$$t = \frac{x\sqrt{k}}{c}$$

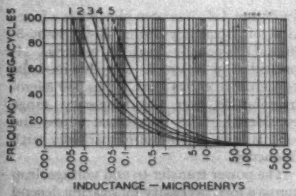

Figure 7. Ideal tuning inductances required as a function of frequency for loads of specified capacitance

1—C = 500 micromicrofarads
2—C = 300 micromicrofarads
3—C = 150 micromicrofarads
4—C = 100 micromicrofarads
5—C = 50 micromicrofarads

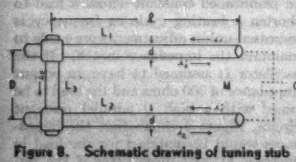

Figure 8. Schematic drawing of tuning stub

L_1, L_2—Parallel conductors
L_3—Movable short-circuiting bar
i_1, i_2, i_3—Primary currents
i_1', i_2'—Induced currents
C—Distributed capacitance

so that

$$V = V_{max} \cos 2\pi f \left(\frac{x\sqrt{k}}{c}\right) \tag{9}$$

in which

V_{max} = maximum voltage
x = distance from point of maximum voltage
k = dielectric constant of medium between electrodes
c = velocity of light
f = frequency

If it is assumed that a ten-per-cent voltage variation may be tolerated along the greater dimension of a rectangular electrode, it is possible to calculate from equation 9 the maximum permissible electrode length as a function of frequency. These lengths are plotted in Figure 5 and are seen to be considerably reduced as frequency is increased, particularly for media with high dielectric constant. For the data of Figure 5 the generator is assumed to be connected to the mid-point of the shorter edge of the rectangular electrode.

Limitations of Increased Frequency

As the frequency employed is increased, the maximum capacitance, or load, that may be tuned is decreased, because practical tuning inductances may not be devised below a certain minimum inductance value. In order to absorb energy from the oscillator in the arrangement shown schematically in Figure 6, the load must be tuned to approximately resonance at the frequency of the source in accordance with the basic condition for resonance:

$$f = \frac{1}{2\pi}\frac{1}{\sqrt{LC}} \tag{10}$$

where

f = resonant frequency
C = capacitance of load
L = inductance of tuning element

Speaking practically, the load is best tuned just above resonance on the capacitative side as operation at this point is more stable and efficient than either at resonance or on the inductive side of resonance. As shown in Figure 6 for parallel resonance, probably the most common load-circuit connection in industrial dielectric heating, this means the load presents nearly maximum impedance to the source, a condition favoring the high voltage across the load electrodes necessary to produce inphase heating current. In a series-resonant arrangement tuned near resonance, the load presents nearly minimum impedance giving rise to high transmission-line currents and corresponding losses. This undesirable feature, together with the fact that in a series arrangement the voltage across the capacitor is greater than the impressed voltage by a factor, Q, which frequently causes voltage breakdown, has led to the more widespread use of the parallel connection. However, equation 10 holds for the series case; and, if the voltage across the electrodes is identical, the facts of this analysis apply to either parallel or series connection unless otherwise stated.

Equation 10 defines the resonant frequency strictly for the case of zero resistance in the load circuit. Although the residual resistance of such a parallel circuit reasonably may be neglected, the effective series resistance, R_s, of the dielectric should be considered, leading to a shifted resonant frequency defined:

$$f_r = \frac{1}{2\pi}\frac{1}{\sqrt{(L - CR_s^2)C}} \tag{11}$$

However, for the materials whose dielectric properties are shown in Figure 3 (that is, $\cos\theta \leq 0.1$) this correction is negligible. If C is assumed constant the change in frequency may be defined as

$$\frac{f_r}{f} = \sqrt{1 + \cos^2\theta} \tag{12}$$

where

f_r = resonant frequency with resistance
f = resonant frequency with zero resistance
$\cos\theta$ = power factor of material

More important is the fact that the term CR_s^2 in equation 11 diminishes as the temperature of the dielectric is increased owing presumably to changes in k and $\cos\theta$ with temperature. Because of incomplete information regarding the effect of temperature on these dielectric properties, it can only be said that, as the temperature of the load is increased, less tuning inductance is required.

It is evident, from equation 10 that, as the load capacitance is fixed, at least at the beginning of the heating cycle, it is necessary to reduce the inductance of the tuning element in order to resonate the fixed load at higher frequencies. In Figure 7 are plotted, from equation 10

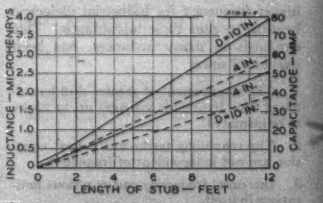

Figure 9. Calculated L and C characteristics of tuning stub of Figure 8 as a function of conductor length and separation

D = conductor separation
Conductor diameter—1 1/8 inches
Solid line—Inductance
Dashed line—Capacitance

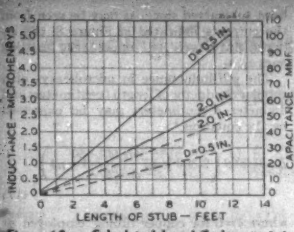

Figure 10. Calculated *L* and *C* characteristic of tuning stub of Figure 8 as a function of conductor length and diameter

D = conductor diameter
Conductor separation—8 inches
Solid line—Inductance
Dashed line—Capacitance

for pure *L* and *C*, the inductances required to tune loads of 50 to 500 micromicrofarads over a frequency range from 10 to 100 megacycles. Although it is recognized that these frequencies are shifted by the effective series resistance of the dielectric and the latter's rise in temperature during the heating cycle, they are sufficiently accurate for illustrative purposes. So far as temperature rise of dielectric is concerned, the inductances presented are maximum required values for a particular load geometry. The 500-micromicrofarad capacitance corresponds approximately to a 2.25-cubic foot 108-pound load of material *A* in Figure 3 at room temperature. Although ideally inductances of the order of magnitude of those indicated would be possible, there exists, however, a practical lower limit for an inductance suitable to tune a load dissipating a large amount of high-frequency power.

Such loads have been successfully resonated by means of a so-called tuning stub, that is, two parallel copper pipes connected with a sliding cross piece or short-circuiting bar, as is illustrated in the schematic drawing of Figure 8. In Figure 9 are plotted the *L* and *C* characteristics for tuning stubs from 0 to 12 feet in length, separated four and ten inches, respectively, and made from $1^3/_8$-inch-outside-diameter copper pipe. Variation of *L* and *C* as a function of conductor diameter is shown in Figure 10. The calculations, for which the details are presented in the appendix are ideal to the extent that zero capacitance to ground has been assumed for the stub. It is apparent, from an examination of Figures 9 and 10, that 0.1 to 0.15 microhenry is the minimum calculated inductance that may be expected from such an arrangement. Furthermore, the tuning stub does not act as an inductance under all circumstances, an additional limitation on the maximum capacitance that may be tuned at a specified frequency. As there is always capacitance associated with the inductance of a stub, the latter has a natural or resonant frequency. When the frequency of the voltage applied to the stub is in excess of the natural frequency, the stub presents a capacitative impedance and is no longer useful as a load-tuning element. At intermediate frequencies the effective inductance of the stub may be computed from the approximate formula:

$$L_{eff} = \frac{L}{1-\gamma^2} \qquad (13)$$

where

L = calculated inductance
γ = ratio of actual to resonant frequency (accurate for $\gamma < 0.8$)

In Figure 11 has been plotted the resonant frequency of the stub in question with a conductor spacing of ten inches. The frequencies corresponding to each length are the maximum frequency at which the stub presents an inductive impedance. Of course, if some capacitance to ground had been assumed, these maximum frequencies would be reduced.

The data of Figures 9 and 11 and experience have led to the conclusion that a straight piece of tubing one foot long may be taken to represent the practical minimum inductance that may be employed as a load-tuning element. The calculated inductance of such a length of tubing $1^3/_8$ inches outside diameter is 0.149 microhenry. In practice there arises the necessity of shielding such an element to avoid interfering radiation. A cylindrical grounded shield of eight-inch radius introduces a capacitance to ground of 6.91 micromicrofarads, from which information the effective inductance may be computed as a function of frequency. From equation 10 the maximum effective capacitance that can be tuned can be calculated. If an inherent inductance of 0.00006 microhenry per micromicrofarad is assumed in the load of Figure 1, its geometrical capacitance may be computed from the relation:

$$C = \frac{C_{eff}}{1+4\pi^2 f^2 C_{eff}} \qquad (14)$$

Based on these assumptions, the maximum geometric capacitance that may be tuned by conventional methods has been plotted as a function of frequency in the curve labeled "practical" in Figure 12. These maxima are to be compared with those of the curve designated "ideal" in Figure 12 computed for the case of pure *L* and *C*. It is apparent that, if the 500-micromicrofarad 2.25-cubic foot 108-pound load already referred to is to be tuned by ordinary means, the frequency should not exceed approximately 20 megacycles.

There are means by which the maximum tunable capacitance may be increased, but such means are not feasible in all cases. The capacitance of a load may be halved by connecting a similar

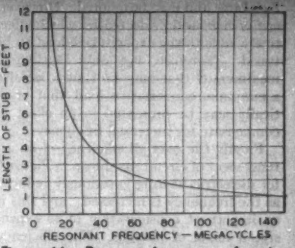

Figure 11. Resonant frequency of tuning stub of Figure 8 as a function of conductor length

Conductor separation—10 inches
Conductor diameter—$1^3/_8$ inches

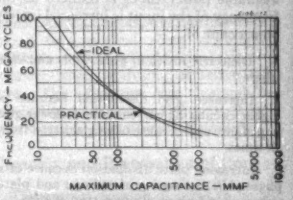

Figure 12. Maximum tunable load capacitance as a function of frequency, if 0.149-microhenry minimum practical tuning inductance is assumed

Ideal—Pure *L* and *C*
Practical—Residual parameters

capacitance in series; but if the additional capacitance is air-insulated it robs part of the available voltage from the load, and if it is a duplicate load the power requirements are doubled, which may prove uneconomical. Bierwirth and Hoyler[1,2] have ingeniously tuned a 700-micromicrofarad load at 45 megacycles by means of multiple-tuning stubs each of minimum inductance, which incidentally tune out the standing waves that would otherwise appear on the load electrodes. However, such a scheme is of limited application.

It should be emphasized that the impedance across a capacitative load is diminished as the frequency is increased. Quantitatively, this impedance is expressed for the general case:

$$Z_C = \frac{1}{2\pi f C}\sqrt{\cos^2\theta + 1} \qquad (15)$$

where

f = the frequency employed
C = capacitance
$\cos\theta$ = power factor of medium

Relatively small stray capacitances to ground frequently exist in a practical dielectric-heating load. As the medium is usually air ($\cos\theta = 0$), for low frequency

Z_c is large and may be ignored. However, as f is increased Z_c decreases, which effectively adds to the capacitative load to be tuned. Therefore, not only is there a maximum C that may be tuned but also a minimum capacitative load that practically may be presented in an effort to compensate for increased frequency.

Finally the over-all efficiency of an arrangement of circuits as shown in Figure 6 for dielectric heating is seriously reduced as the frequency is increased; and this is an important consideration in so expensive a mode of heating. The efficiency should be kept between 50 and 60 per cent for economic operation. Not only are there resistive and radiation losses throughout the circuits, but an inherent limitation is the efficiency of the oscillator power tubes. The plate efficiency of available power tubes is reduced as the frequency of the input is increased largely on account of

1. Dielectric losses in glass walls and elsewhere.

2. Increased grid dissipation because of higher circulating currents due to lower grid impedance and because of long electron transit times.

3. Increased plate dissipation because of a phase shift between grid voltage and plate voltage due to long electron transit time.

Although plate efficiency data are not available, rated reduction in power input for several oscillator tubes that may be used for industrial dielectric heating with output power up to 100 kw has been plotted versus frequency in Figure 13. A conventional triode will function with 60-70-per-cent plate efficiency up to 20 megacycles. Above this frequency losses increase until at approximately 100 megacycles losses equal input power and the tube ceases to oscillate. It is apparent that, if higher frequency is required for shorter heating cycles, limited power output must be anticipated but not necessarily with reduced input power.

Choice of Frequency

In conclusion it must be emphasized that in reality the choice of frequency for a dielectric-heating application is a compromise among

1. The geometry of the load.

2. The electrical characteristics of the material constituting the load.

3. The oscillator tubes available.

Frequency must be selected with these factors clearly in mind, as well as the desire for minimum duration of heating cycle.

Broadly speaking, as high a frequency as is practical, available, and economical should be used. In particular, highest frequency is suited to very small loads,

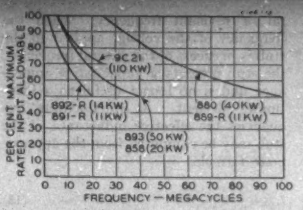

Figure 13. Allowable percentage of maximum rated input as a function of frequency for certain power tubes suited to dielectric heating

thin sections not capable of insulating high voltages, and materials with low loss factor. There is a limit to the extent that frequency may be increased to accommodate thin sections because, as thickness diminishes, load capacitance increases, presenting a serious tuning problem. Emphasis on high frequency to obtain short heating cycles may frequently be misplaced because

1. Extraneous circumstances often set a practical lower time limit to acceptable heating cycles.

2. Too rapid heating may have a deleterious effect on the material.

3. Increased production rate may not be economical unless accompanied by increased volume of production.

This analysis of the role of frequency in industrial dielectric heating indicates that at least for several years to come the range of frequency from 10 to 30 megacycles only will be utilized for large-scale dielectric heating, that is, for powers up to 100 kw. Changes in dielectric properties with elevated temperature will make close frequency control difficult unless means of automatic tuning are devised. Therefore, users and suppliers should coordinate their research and development activities with these facts in mind.

Appendix. Calculation of L and C for Tuning Stub

The total inductance L_T of the tuning stub shown schematically in Figure 8 may be calculated from the relation:

$$L_T = L_1 + L_2 + L_3 - 2M \tag{16}$$

where

L_1 = self-inductance of first conductor
L_2 = self-inductance of second conductor
L_3 = self-inductance of short-circuiting bar
M = mutual inductance between first and second conductors

It is apparent that the relatively small mutual inductance between the short-circuiting bar and the other conductors has been neglected. The mutual-inductance term has been subtracted since, as may be seen from the currents indicated in Figure 8, the induced currents i_3', i_4' oppose the existing ones i_3, i_4.

The self-inductance in microhenrys of a tubular conductor of length l centimeters and diameter d centimeters may be expressed by the equation:[3]

$$L = 0.002l\left(2.303\log_{10}\frac{4l}{d} + \frac{d}{2l} - 1 + \mu\delta\right) \tag{17}$$

where $\delta \approx 0$ for copper tubing employed at frequencies above one megacycle. The mutual inductance in microhenrys of two parallel conductors of length l centimeters separated by a distance D centimeters from center to center as in Figure 8 may be computed from the relation:[3]

$$M = 0.002\left(2.303l\log_{10}\frac{l+\sqrt{l^2+D^2}}{D^2} - \sqrt{l^2+D^2} + D\right) \tag{18}$$

When equations 17 and 18 are substituted in equation 16, the total inductance L_T of the tuning stub may be simplified to the form:

$$L_T = 0.004l\left(2.303\log_{10}\frac{4lD}{d(l+\sqrt{l^2+D^2})} + \frac{d+2\sqrt{l^2+D^2}-2D}{2l} - 1\right) + L_4 \tag{19}$$

Where L_4 is the self-inductance of the short-circuiting bar, which may be computed from the relation:

$$L_4 = 0.002D\left(2.303\log_{10}\frac{4D}{d} + \frac{d}{2D} - 1\right) \tag{20}$$

The values of tuning-stub inductance plotted in the curves of Figures 9 and 10 were computed from equations 19 and 20.

The tuning stub in question is, of course, not pure inductance but has a certain distributed capacitance between the parallel conductors that has been represented in the schematic drawing of Figure 8. If the effect of the short-circuiting bar is neglected and the conductors are assumed to be infinitely removed from ground, this capacitance in micromicrofarads may be computed from the relation:

$$C = \frac{0.1208l}{\log_{10}\frac{2D}{d}} \tag{21}$$

where l is length of conductors in centimeters and D is their separation in centimeters, center to center. The values of capacitance for the tuning stub plotted in Figures 9 and 10 were computed from equation 21.

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1. Radio-Frequency Heating Applied to Wood Gluing, L. A. Bierwirth, C. N. Hoyler. *Proceedings* Institute of Radio Engineers, volume 31, 1943, pages 529–37.

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Rewinding Commutator-Type Traction Armatures

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THE AMERICAN RAILROADS achieved more than twice as many passenger-miles and hauled twice as many ton-miles of freight in 1943 as in the corresponding period of 1918. Incomplete reports indicate increases for 1944. This enormous job is being done with smoothness and dependability and with far less congestion than was possible with the equipment and personnel of World War I.

Locomotives with electric transmissions, which include straight electric, Diesel-electric, and gasoline motorcars, and their attendant electric equipment, have played an important part in this accomplishment. With the increased number of electric locomotives in use, the longer hours of operation, and the heavier loads, old maintenance problems have been accentuated; new ones have arisen. Down the long list of these problems is one entitled "Armature Rewinding."

The object of this paper is to review for those experienced in the art of armature rewinding and to cite for the newcomer some of the important and frequently overlooked factors which must be considered to restore a damaged armature to its original condition and to modernize and improve, consistent with current practices. The factors will be discussed under the following headings:

1. Analysis of failure.
2. Cleaning.
3. Magnetic inspection.
4. Commutator.
5. Rewinding materials.
6. Armature windings.
7. Banding.
8. Impregnating.
9. Balancing.

Railway armatures present an interesting though difficult problem as they must withstand the severe strains imposed upon them by varying loads at varying speeds,[1] plus the several combinations of vibration and strains resulting from train motion and roadbed shock, and often with rapidly changing ambient temperatures.

Analysis of Failures

Traction motors are of necessity rugged in design because of inherently severe duty requirements. The kind of service is such that road failures must be kept at a minimum, not only because of the direct cost but because of the consequent expense incurred when traffic movement is obstructed. In most industrial plants a replacement motor or part can be installed in a comparatively short time. With motive power, however, the point of operation is not fixed and failures may occur many miles from the nearest repair or exchange facility.

In spite of equipment design and operating precautions taken to prevent failures, they will happen. To minimize these failures, an analysis of the cause of each must be made and steps taken to lessen the possibility of a recurrence.

Figure 1. View of vapor cleaning tank

Powerful cleaning action is effected by hot vapors condensing on the object to be cleaned by virtue of:

1. Strong solvency of cleaning fluid
2. Distilled vapor is full strength, undiluted by dissolved grease
3. 188 degrees Fahrenheit temperature helps to clean and to cook off paints and varnishes

Causes of armature failure can be divided into two classes:

1. Those which can be attributed to faulty operating conditions.
2. Those originating within the motor due to mechanical or electrical defects.

Causes of armature failures may be numerous and varied; however, some of the major and frequently occurring troubles are discussed in the following paragraphs. The armature winding may be completely roasted because of a mechanical fault causing excessive overload; it may be roasted because of heat resulting from friction generated when worn-out bearings or journals allow the armature to rub the pole pieces. The armature winding or commutator may be grounded, short-circuited, or open-circuited; bands may fail owing to overspeeding, but in all cases the cause can be assigned to either the category of faulty operation or to that of a defect in the motor proper.

Most failures traceable to a motor defect originate first as a mechanical failure. Improperly seasoned armature insulation caused by incorrect baking and hot banding procedure may permit relative movement of wires or coils which will cause actual mechanical destruction of the insulation and result in an electrical failure. Faulty commutator seasoning on high-speed traction motors, weak brush-holder spring tension, and short or binding brushes are only a few additional things to consider when analyzing armature failures. The advantage of a thorough investigation to determine the cause of each failure cannot be stressed too strongly.

Cleaning and Preparation of Core

The proper cleaning of cores to be rewound goes beyond removing the old coils and scraping out the slots. Grease must be removed, old paint stripped, vent ducts cleared, and the outer surfaces of laminations cleaned. One of the most effective methods of accomplishing these aims is by the use of hot vapor cleaning—a process termed by the sheet-metal industry "degreasing." The equipment consists of a heated tank with a few inches depth on the bottom of the liquid cleaning solution (normally trichlorethylene) and a water-cooled condensing coil around the tank about halfway up the side wall.[2]

In operation, an armature to be cleaned, with its old winding intact, is lowered into the gaseous medium existing between the boiling pan and the condensing coils. As the vaporized cleaning solution is kept at a temperature of 188 degrees Fahrenheit, much higher than the object being cleaned, the vapor condenses upon the object, attacking grease, dirt, and varnish. Condensation is so rapid that the fluid flows from the work in a steady stream, carrying with it dissolved materials. Upon first seeing this action, one would think that liquid was being fed onto the object from an invisible pipe line.

When the entire armature is placed in the tank, not only is the grease and dirt removed but the insulating and bonding varnishes are softened, facilitating the removal of the old winding. This procedure minimizes the hazard of lamination damage when extremely tight coils must be stripped from the slots.

After the temperature of the work has reached that of the vapor, condensation ceases and the cleaning process stops. The

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Figure 2. Clearing surface-fused laminations

armature may be withdrawn from the cleaning tank, and a few strokes with a wire brush removes loose residue and flakes of varnish. If the slots have been dirty, it may be necessary, after removing the coils, to return the stripped core to the cleaning tank for another treatment, but a second cleaning is only occasionally required.

The solvents normally used in this type of apparatus have little or no dissolving effect upon some types of coating materials such as shellac and certain synthetic enamels. The vapors have no effect on water glass (silicate of soda) or other standard lamination-insulating varnishes. Tests reveal that, after these lamination-insulating materials have been suspended in the degreasing vapors for ten minutes, neither their surface smoothness nor adherence to the metal has been affected. A mica commutator segment and cone ring given the same treatment were found to have a very small increase in weight, which was caused by the shellac softening under heat and allowing some vapor to collect. This increase in weight was lost after cooling took place, with no damage to the mica splittings or the shellac bond.

Over a period, repeated dips and bakes build multiple layers of baking varnish on the laminations, in the radial vents, and in the longitudinal core ducts. This insulating coating retards heat transfer and restricts air flow. The removal of this varnish in the "degreaser" will restore original ventilating efficiency to the armature. The elimination of grease from commutator, mica, and cone rings provides a clean surface to which insulating and protective coatings may be applied.

Core laminations of armatures which have failed frequently are found to have been damaged by arcing in slots between conductors and core. Also, the outer surface of core may have been defaced by pieces of conductors or bands being caught between armature and pole faces. Where any of the damage is severe, new core stacking may be necessary. However, after most armature failures, core stacking will not be required.

A very effective method of removing the fused surfaces in the core slots is to grind them out with a high-speed portable tool as shown in Figure 2. Sufficient grinding should be done to clean up all short circuits between laminations. Otherwise, hot spots may be expected to occur in operation, their severity depending principally upon the amount of fusion, the relative location, the magnitude of the armature current, and the frequency.

On older-type armatures having core bands it is often desirable to true up the banding grooves before rewinding. They are often burred over by the tangled mass of banding wire and copper that sometimes gets between the armature surface and the pole piece. An often used practice for accomplishing this is to drive a hard maple block into each slot, filling to the bottom of the band groove, and then, with the armature turning in a lathe, true up burred-over laminations at edges of band groove, taking light cuts with a high-speed tool-post grinder.

Magnetic Inspection

Magnetic inspection is the term applied to the process of examining ferrous metal pieces for flaws by magnetizing the piece and dusting fine iron particles or flowing over the piece a solution with iron particles in suspension. Since different magnetic poles are formed at the cracks, a concentration of the magnetic particles will collect so that the defects can be found by visual inspection.[3]

Magnetic inspection, although not new, has come into common use only since the great forward developments of aircraft, which must, of necessity, use materials efficiently to achieve lightness and safety. Railway equipment, although not limited to the same extent as that of aircraft, is subjected to repeated stresses that may cause costly failures. Armature shafts continuously are subjected to twisting torques while rotating. Improved alloy steels are used for these shafts; however, a metal that is fatigue-proof is not available. Shafts, before complete failure, will develop fatigue cracks. The application of magnetic inspection to traction armature shafts is comparatively recent, and only a limited amount of data are available. The available data indicate that many factors must be evaluated, such as shaft design, the load or torque on the shaft, and frequency of application of loads. The users of traction-motor equipment must compile data on the fatigue of shafts in order that shafts which have reasonable possibility of fatigue cracks may be tested by magnetic inspection.

The general practice in the magnetic inspection of traction armature shafts is to apply the test to exposed surfaces without pressing the shaft from the armature core. One class-1 western railroad has found that most fatigue cracks are detected on the tapered pinion fit adjacent to the bearing fit. This finding has resulted in the following handling procedure for all armatures that are removed from the motor frame for any reason:

1. Remove the pinion and antifriction bearings.
2. Clean all exposed shaft surfaces, removing all grease and dirt.
3. Magnetic-test and inspect for fatigue cracks, fractures, and defects.
4. Check for shaft trueness and alignment.
5. Renew defective shafts.

Fatigue cracks in armature shafts are not limited to the zone between the bearing and pinion fit. If a complete check is wanted, the shaft must be removed and tested over its full length.

Various types of equipment are available for performing magnetic inspection. Some use alternating current, some direct current from storage batteries, and others rectified alternating current for excitation of the magnetic structure.[4] Any type excitation is generally suitable for inspecting traction-motor armature shafts for fatigue cracks. The equipment for checking consists essentially of a magnetic yoke assembly with adjustable pole pieces for contacting the ends of the shaft and an excitation coil with control for allowing current to flow in the coil for comparatively short intervals (0.00001 to 3 seconds), similar to that shown in Figure 3. Magnetic particles in liquid suspension are easier to use, as the solution may be pumped or flowed over the shaft.

Magnetic testing of the wheels, axles, and locomotive crank pins of rolling stock has been used by many railroads for a

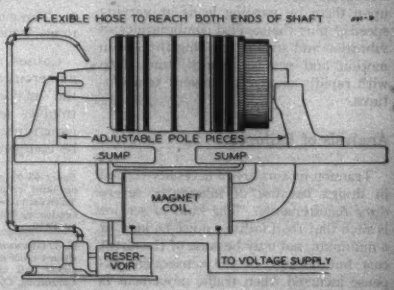

Figure 3. Traction armature in position for magnetic inspection of shaft

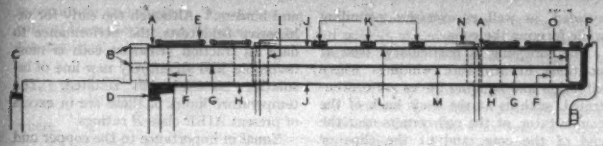

Figure 4. Guide for armature-rewinding materials

See Table III

A—Insulation under bands
B—Commutator-neck fillers
C—Commutator V ring
D—Mica seal
E—Band wire and clips
F—Insulation between coil-end turns
G—Insulation between layers
H—Coil-rest insulation
I—Formed U slot-end insulation
J—Slot insulation
K—Core bands and insulation
L—Strip filler
M—Slot-insulation strip separator
N—Slot stick
O—Coil-connection insulation
P—End-shield insulation

number of years. Some railroads are effectively using the same equipment for testing armature shafts.

Commutators

The condition of a commutator may indicate a real story to the experienced operator. A close examination is, therefore, of prime consideration so that corrective measures can be taken if necessary.

National Electrical Manufacturers Association Standard *RP*4-20 specifies that the Brinell hardness shall be 75 for bars of 0.125 inch and less at the thick edge, 70 for thickness of 0.125 inch to 0.250 inch, and 65 for bars over 0.250 inch. When a commutator shows evidence of having been very hot, it is good practice to test the hardness of the bars and to replace those which are too soft. It is also important on commutator of high peripheral speed that the amount of bar stock depthwise be checked so that there will be no danger of the bar bowing outward because of centrifugal forces. When there is doubt as to the depth of the bar remaining, a check with the commutator manufacturer is warranted. If the depth is less than a safe value, the commutator must be renewed.

After the winding is removed from the armature, the commutator slots are cleaned for the new coil leads, all burrs and fins are removed, and the commutator is given a ground test with the proper test voltage as specified by AIEE Standards. The authors have been unable to find a published Standard for a bar-to-bar test but have used very successfully a value of 220 volts alternating current, 60 cycles.

If the *V* rings are loose or have been disturbed, the commutator should be seasoned before the armature again is placed in service. Many different practices are followed in the seasoning of commutators, and most of them have good points. The object of seasoning is to obtain a tight commutator that will not develop high and low bars after being placed in service. To accomplish this objective we must apply the same elements that produce distortion in service, namely, heat and centrifugal force. The commutator assembly may be rotated in a heating rig and the bolts uniformly tightened at intervals. For the required uniformity in tightening the clamping bolts, it is recommended that a torque wrench be used.

As little copper as possible is removed from the commutator in turning and truing. The point of the tool should be rounded so that a smooth surface results. Final surfacing can be done with a stationary stone mounted in the tool post with the armature running at a high speed. A final polish may be given with a hand stone or very fine sandpaper. The commutator should be true within 0.001 inch for any high-speed motor. Where greater precision is wanted, the commutator may be ground with a carborundum wheel while the armature is rotated at full speed in its own bearings in a special grinding rig.[4]

Undercutting of commutator mica segments first came into use over 35 years ago, and, though at first it was not accepted, there is today little occasion to doubt its merits. However, expert care must be exercised in the operation, or the merits of undercutting are lost. It is very important that all mica fins be removed, as they are frequently the source of unsatisfactory operation. After undercutting, the rough corners of the copper bars must be removed.

After the commutator has been finished, it should be cleaned thoroughly and the armature blown out to remove all the copper chips and dust. It should be inspected carefully and then given a ground test according to AIEE Standards.

The protection of the outside surface of the *V*-ring mica that projects beyond the commutator can be accomplished readily by applying a coat of shellac, running over this a single layer of Fiberglas braid, and coating repeatedly with red enamel, sandpapering between coats. This will result in a very smooth surface which will minimize the collection of dust and oil.

Table I. Banding Tension

Brown and Sharpe Gauge	Diameter (Inches)	Grade-C Steel and 18-8 Stainless Steel *Tension (Pounds)	Phosphor Bronze *Tension (Pounds)
8	0.128	850	600
10	0.102	600	400
12	0.081	400	250
14	0.064	250	160
16	0.051	160	100

* When double-deck bands are used, reduce the tension values by ten per cent for the top band.

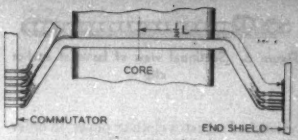

Figure 5. Increase in length of armature-coil bars from copper expansion

One-half length at 20 degrees centigrade = 17.000 inches
One-half length at 125 degrees centigrade = 17.036 inches
One-half length at 200 degrees centigrade = 17.058 inches

Rewinding Materials

An often overlooked important element of armature rewinding is engineering planning of the rewinding materials. Rewinding materials include all insulation, solder, band wire, and like material, exclusive of the coils. Figure 4 gives the location of various items of rewinding material, and the table therewith will serve as a general guide to good practice in the use of material with AIEE class-*A* and class-*B* windings. Precision armature rewinding necessitates complete drawings of the armature assembly with detailed instructions on the method of application of each item of rewinding material. Information gathered from the analysis of failures is a part of the engineering data required for preparation of these rewinding specifications. Each item of rewinding material must be engineered for its job.

Too often certain items of insulation are applied to an armature, because it has been customary to use insulation in that particular spot on similar equipment. Frequently overlooked in applying rewinding insulation are:

1. Formation of pockets for trapping carbon dust and other foreign material.
2. Obstruction of ventilation.
3. Formation of dead air pockets.
4. Use of materials that are heat insulators.

These factors weigh heavily in the selection of proper rewinding materials. As an example, the material under the bands is preferably of a cushioning nature such as

Figure 6. Sectional view of band at anchor clip

varnished asbestos cloth or paper, in order that the material will not chafe and disintegrate with winding movements resulting from expansion, contraction, acceleration, and deceleration.

Economical rewinding requires that many items of the insulation be precut and fabricated. Volume production permits the use of tools and dies for shaping the rewinding material to greater accuracy than is possible by hand cutting and shaping. Better-quality workmanship may be expected by the use of packaged precut rewinding material, along with complete instructions for its use.

Armature Windings

The most important factors to be considered in the design, fabrication, and installation of armature and equalizer coils are copper fatigue and insulation deterioration. The number of turns, span, connections, copper size, and arrangement, and minimum dielectric requirement of windings are factors fixed for a given set of electrical characteristics. Changed operating requirements or need for modernization may necessitate the altering of one or more of these factors. When such is the case, it is an electrical-design problem, and complete design analysis should be made.

Copper fatigue and the resultant wire breakage in armature windings can be attributed to many causes, and there are equally as many devices for countering the supposed causes. There are, however, some fundamentals that must be followed to minimize copper failures.

The basic copper must be of the highest quality and the most fatigue-resistant available. Several premium coppers having superior properties are obtainable under various trade names. Soft annealed copper is generally accepted as desirable; any severe strains set up in the copper grain structure by edge bending, swaging, and similar cold working should be relieved by annealing. Surface scratching and nicking the copper must be avoided, as well as excessive pounding while forming the coils.

Table II. Acceptable Limits of Unbalance

Maximum Speed (Rpm)	Amplitude Unbalance at Bearings (Inch)		
	Fair	Good	Very Smooth
600	0.004	0.0025	0.0013
900	0.003	0.0016	0.001
1,200	0.002	0.0015	0.0007
1,500	0.0016	0.001	0.0006
1,800	0.0013	0.0008	0.0005
2,400	0.0009	0.00051	0.0003
3,000	0.0006	0.0004	0.0002
3,600	0.0005	0.0003	0.0002

The foregoing is particularly true at positions in armature windings where vibration and bending forces are concentrated, such as at the leads back of the commutator, at the coil corners near the end of the core, and at the clips or knuckles. Prominent among the several causes of bending forces is the linear expansion and contraction of the copper wire.

Figure 5 shows the amount of increase in length of an armature-coil bar from expansion caused by increased temperature. The dotted loop at the end of the slot portion illustrates coil distortion at a position where a large portion of this increased metal length is relatively free to be relieved. After the armature body has absorbed some heat, the increased copper length relative to the core is then a function of the difference in coefficients of expansion of the copper and the steel of the armature. It is not so much the difference between the coefficients of expansion of the two metals that causes the trouble but rather the wide difference in their temperature. The increase in copper length from expansion relative to the core is greatest when heavy starting currents flow through a cold armature; however, there is a continual variation in coil length during operation, caused by the variable-type load on traction motors.

This changing of coil length and resultant bowing of the coil at the end of the slot section not only contributes to copper fatigue but also disturbs the coil insulation; and the same heat that causes the expansion and contraction accelerates thermal aging of the insulation. In time, flexible coil insulations will be destroyed by heat and movement.

All modern traction armature windings are fabricated with class-*B* insulation, having an AIEE (Standard 11) temperature rating of continuous operation at 120 degrees centigrade above ambient. Often, higher temperatures are reached in operation, and the best of insulating materials are strained to their limit.

Class-*B* insulation covers a wide variety of combinations of inorganic substances in conjunction with organic bonds and backing materials. Some maintain their flexibility after being subjected to prolonged high temperatures, whereas others become brittle and lose their ability to withstand movement. The backing materials normally used are organic papers and fabrics; however, in some instances inorganic paper and cloth are used. There are applications where each of the different backings may have advantages. In recent years Fiberglas cloths, some as thin as 0.00175 inch and 0.002 inch, have proved highly successful for class-*B* backing materials. Along with the step-up in inorganic content of class-*B* material, we now have a new heat-stable organosilicon-oxide polymer in the form of varnishes and binders.[6] Although too early for exhaustive field tests, the performance to date on traction armature coils is most favorable, and an entirely new line of insulating materials has resulted. The temperature limits of these are in excess of present AIEE class-*B* ratings.

Equal in importance to the copper and insulation consideration is the proper installation and physical fit of the armature windings. The size of the slot portions must be held to a very close tolerance and must be correct for a tight drive fit without the necessity of adding filler materials. However, rather than have coils loose in the slot, it is preferable to use even organic fillers, though mica is the normally accepted material. A tight-fitting coil may be driven into the slots with less hazard of damage by painting with an insulating varnish just prior to installation. The wet varnish serves as a lubricant and, after it sets, provides a bond between the coils and the core.

The coils must be shaped so that when they are installed the preformed copper will lie in its normal position without setting up strains and binding points.

The point at which the coil slot section leaves the core lamination is hazardous in any winding and is even more so on railway-type armatures. The distortion from expansion shown in Figure 5 and the forces caused by vibration and by inertia of the end windings concentrate combined motion and pressure between the coil and the ends of the core lamination. The slots of many armatures are recessed at their ends to accommodate a U-shaped piece of heavy paper or fabric, thus affording a cushion and method of distributing the strain. Where recesses in the core may not have been provided, another effective method of minimizing strain concentration is to taper the core slot from $^1/_{32}$ to zero inches for about one-half inch back into the core, rounding off the outer edges.

The placement of the various insulations should be executed in accordance with carefully prepared drawings especially for the armature under consideration and made along the lines as shown in Figure 4.

Banding

A properly cleaned and insulated armature core and the correct use of insulating materials and coils must be complemented by carefully considered banding procedure. The quality of the finished armature may be lowered, unless the same careful planning is given to the banding method, as has been followed in the other steps of armature rewinding.

To calculate the load which the bands must carry, the usual procedure is to consider as separate problems the stresses in each of three sections of the winding, that is, the pinion end, the core section, and the

commutator end section. The stresses in each of these sections can be calculated by the empirical formula:[7]

$$S = 3.25 \times \left(\frac{\text{rpm}}{1{,}000}\right)^2 WD$$

where

S = stress on the bands in pounds
W = weight of coils, including insulation and band wire in the particular section under consideration
D = armature diameter in inches

(For core bands use a constant of 2.8 instead of 3.25.)

After the value of S has been determined for each end and for the core section (except when slot wedges are used), a suitable-size wire is selected. The allowable tension per wire for the wire size chosen is given in Table I. Divide this value into the stress to get the number of wires required in each band. On coil ends use double-deck bands, if necessary, to accommodate the required number of wires.

Steel wire having a tensile strength of 240,000 to 270,000 pounds per square inch generally is used for banding armatures. However, to reduce commutation voltage and band losses, a nonmagnetic band wire is desirable on higher-speed traction armatures. Nonmagnetic stainless-steel wire is used in preference to phosphor bronze because of its greater tensile strength, 225,000 to 256,000 pounds per square inch, as compared to 130,000 to 150,000 pounds per square inch for phosphor bronze. The band wire must be of such quality and toughness that it can be bent 180 degrees on itself without breaking.

The anchoring of the ends of the band wire is most important, and it should be such that it will hold even after the solder may have melted and thrown off.[8] A frequently used method satisfying this requirement of fastening the band-wire ends is shown in Figures 6 and 7, which are, respectively, a section and a plan view. This method is applicable principally to bands on the end windings, because core-band grooves normally do not have sufficient space for the double folded-over clip. A good method for applying core bands is, first, to insulate each band groove with a layer of saturated 0.010-inch asbestos paper, over which is placed a strip of 0.015-inch tinned copper. Apply the band on the tinned-copper strip, using standard folded-over band clips, and solder to form a solid mass of band wire, copper strip, and clips.

The intermediate band clips normally are made from tinned copper and are usually spaced five or six inches apart, except at the beginning and ending of the band, at which point the clips are placed closer together. The number of clips must be an odd number that is not a multiple of any whole number divisor of the number of poles in the machine or closer than ten per cent (more or less) of the number of poles.[9]

Temporary "hot banding" is necessary on traction armatures to insure against lack of solidity that may lead to premature failure. Hot banding is accomplished by heating the armature to 250 degrees Fahrenheit before soldering the leads into the commutator and before brazing coil-connection clips where they may be used. A temporary band is run over the hot armature from the commutator riser to the pinion end of the windings. The end windings are protected with a cushioning pressboard strip under the band, and a filler strip of metal, fiber, or hard wood is placed in each slot projecting above the slot.

In the case of a wedged armature, install band clips so that the core portion of the temporary band can be removed for wedging with the end bands in place. After the slot wedges are in and before removing the temporary end bands, solder and braze the windings as required

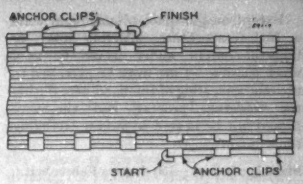

Figure 7. Plan view of beginning and ending of band wire showing method of anchoring

and then dip and bake the armature according to established standards. After the armature has cooled to room temperature, remove the temporary bands and apply the band insulation and permanent bands.

It is very important that the tension be uniformly applied. There are a number of tension devices on the market which control and uniformly apply any prescribed tension, the amount of which should not be a matter of guess. The values in Table I have proved satisfactory.

Table III. Guide for Armature Rewinding Materials

See Figure 4

Type	Position	Use With AIEE Class-A Coils	Use With AIEE Class-B Coils
Core	Coil rests	Pressboard or tapings of varnish cloth and cotton tape	Flexible mica, oiled asbestos paper or 0.030-inch varnished glass cloth, tapings of glass tape, molded mica rings
	Coil shield	Rope paper and varnished cloth	Flexible mica and 0.030-inch varnished glass cloth, molded mica rings
Slot	Troughs or cells	Fish paper or high-density rag paper	Preferably none—use uncut mica if filler is needed
	U end pieces	Rag pressboard	Treated asbestos tape
	Bottom fillers	Pressboard, fish paper, or high-density rag paper	Sheet bakelite, oiled asbestos paper, or molding mica
	Coil separators	Pressboard, fish paper, or high-density rag paper	Sheet bakelite, oiled asbestos paper, or molding mica
End	Between layers	Treated duck or rag pressboard	Oiled asbestos paper
	Between leads and knuckles	Treated duck or high-density rag paper	Flexible mica or 0.030-inch varnished glass cloth or Mica-Glas combination
	Between knuckles or rear coil connections	Treated duck or high-density rag paper	Flexible mica or 0.030-inch varnished glass cloth or Mica-Glas combination
	Between coil end turns	Treated duck or high-density rag paper	Glass, asbestos, or canvas-base bakelite, molding mica
Wedges or sticks	Coil retainer or protective strip	Canvas-base bakelite	Asbestos-base bakelite, glass-base bakelite, or canvas-base bakelite
Band	On core	Fish paper, rag paper, or rag pressboard	Uncut mica or varnished asbestos paper
	On coils	Treated duck, fish paper, or high-density rag paper	Flexible mica and oiled asbestos paper or varnished asbestos cloth
Miscellaneous	Commutator seal	½-inch flax cord painted with Red Commutator Enamel	½-inch glass braid painted with Red Commutator Enamel
	Band wire	Tinned steel, grade C-1, or tinned 18-8 stainless steel	Tinned steel grade C-1 or tinned 18-8 stainless steel
	Band clip	Tinned steel or tinned copper	Tinned steel or tinned copper
	Solder	50 per cent tin—50 per cent lead or Alloys upward to 100 per cent tin	100 per cent tin, 95 per cent tin—5 per cent antimony, or high-temperature alloy
	Flux	Nonacid rosin flux	Nonacid rosin flux
	Dipping varnish	Synthetic black baking	Synthetic black baking
	Spray varnish	Black oilproof air-dry	Black oilproof air-dry

Except on phosphor-bronze band wire; a high-temperature soldering alloy or high-tin-content solder should be used when possible. Care must be exercised to prevent annealing of the band wire during the soldering process, and the wire should not be heated to values exceeding those below:

Phosphor bronze—450 degrees Fahrenheit

Plain steel—600 degrees Fahrenheit

Nonmagnetic steel—1,000 degrees Fahrenheit

Solders having a liquefaction point higher than 450 degrees Fahrenheit should not be used on phosphor-bronze band wire.

Impregnation

The proper varnish treatment ranks close to the top of the list of those things that may be done to improve the quality of a winding, and yet it is one of the least expensive to execute. Consequently, it would be imprudent to use anything but the highest-grade insulating varnish and the best method for treating and baking.

Most of the varnish manufacturers have a top-grade varnish; and although there may be many formulas for producing such a material, the generally preferred properties are:

1. Long life at elevated temperatures.
2. Deep-drying ability.
3. Only slight resoftening under heat.
4. Toughness.
5. Resistance to oil, moisture, and chemical attack.
6. Good wet and dry dielectric strength.
7. Satisfactory viscosity for proper draining and build-up.
8. Reasonably safe flash point.

Vacuum-pressure impregnation usually is accepted as the best method of application for the initial treatment followed by one or two dips. The impregnating cycle may require 10 to 12 hours elapsed time, 1 hour preheat, 3 hours vacuum, 3 hours pressure, and 3 hours draining. During this treatment, the innermost parts of the winding become saturated and coated, even though more than half the varnish forced in may drain or "bleed" out during baking. The additional varnish dips fill surface cracks and voids, providing a protective film over the entire winding.

A good impregnation and dip treatment bonds and solidifies the entire winding, resulting in:

1. Increased heat conduction.
2. Sealing out dirt, oil, and other foreign materials.
3. Improved and prolonged life of insulation.
4. Less damage from mechanical shock.
5. Moisture resistance.

The armature should be baked after impregnation and after each dip in a well-ventilated, preferably recirculating-air-type, oven at from 250 to 275 degrees Fahrenheit. The time, of course, depends upon the drying properties of the varnish, characteristics of the oven, and the physical size of the armature. A typical baking cycle for a 400-horsepower high-speed traction armature with 18-inch-diameter by 16-inch-long core, using a high-grade synthetic varnish of the afore-mentioned general properties is as follows:

1. Preheat in oven one hour at 250 degrees Fahrenheit.
2. Allow to cool to 90 degrees Fahrenheit before placing in vacuum tank.
3. Bake 12 hours at 275 degrees Fahrenheit after impregnation.
4. Bake 12 hours at 275 degrees Fahrenheit after first dip.
5. Bake 18 hours at 275 degrees Fahrenheit after second dip.

It is usually desirable to permit the armature to cool to approximately 100 degrees Fahrenheit before each dip. This procedure gives a heavier film build-up and minimizes polymerization of the heat-reactive varnish in tank.

Dynamic Balancing

Traction drives are using higher-speed motors to obtain better efficiency and lighter weight as is evidenced by the increase in peripheral speeds from 8,000 to 12,000 feet per minute during the past 25 years. Motors operating at these speeds must have precision-built dynamically balanced rotating members. An unbalanced armature may destroy antifriction bearings, break armature-coil leads, damage gearing, and cause bad commutation, and, in addition may have undesirable physiological effect.

Modern-designed rotating elements usually have provisions for fastening the dynamic-balancing weights, though the methods may vary widely. Some units have grooves on both the pinion and commutator ends into which the counterbalancing weights are electrically welded. Others require the fastening of the weight by bolts secured against loosening by lock plates. Practically all traction-motor armatures are dynamically balanced by their maker after assembly of the spider, laminated core, and commutator, and before the application of the windings. This minimizes the amount of balancing weights required after the armature is wound and finished. Various types and designs of machines are available for dynamic-balancing operations.

Figure 8 illustrates a traction-type armature mounted in a balancing machine for dynamic balancing.

Experience of the operator is a large factor in the quality and cost of the operation, irrespective of the machine. The tolerances to which the armatures are dynamically balanced affect the cost. The various balancing machines do not have indicators measuring in the same units such as ounce-inches or thousandths-of-inch amplitude. Table II gives limits of unbalance that have proved acceptable.[10] The values in this table are in thousandths-of-an-inch amplitude as measured at the motor bearings. (Amplitude is the extent of the vibratory movement measured from one extreme to the oppo-

Figure 8 (left). Traction armature in dynamic-balancing machine

Figure 9 (right). Traction motor being checked for unbalance with vibrometer

Per-Unit Impedances of Synchronous Machines

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THE ANALYSIS of synchronous machinery is dependent upon a correct and complete knowledge of the machine impedances. The progress of synchronous-machine analysis has been characterized by the recognition of an increasing number of rotor circuits and by an accompanying need for accurate numerical data on the impedances of these additional rotor circuits. The modern equivalent-circuit method of analysis demands an almost limitless array of impedances involving not only mutual reactances but mutual resistances as well. As the application engineer, confronted by more complex application problems, has created more complete equivalent circuits, he has demanded of the design engineer accurate numerical data on the impedances of additional rotor circuits previously ignored. The design engineer himself has been confronted with more complex design problems which have made him directly cognizant of the need for more complete impedance data.

It is the purpose of this paper to present generalized formulas by means of which the per-unit impedances of the new additional rotor circuits may be calculated directly from the physical impedances (in ohms and henrys), and by means of which these new per-unit impedances can be made consonant with the per-unit impedances of rotor circuits previously analyzed.

The technical literature contains several articles which give design formulas for many machine impedances, but these articles are all characterized by the desire to present the impedance formulas in a per-unit form immediately applicable to routine design calculations. This practice is commendable to some degree, since correct numerical impedances usually are obtainable from these published formulas, but in a broader sense is to be deplored. The published per-unit formulas not only tend to obscure the physical characteristics of the various impedances, but they also imply that all per-unit impedances are unique and single-valued when expressed "in per unit of the machine kilovolt-amperes and voltage." This paper will show, however, that, if those impedances which are measurable from the machine terminals are neglected, all machine impedances are multivalued when expressed only in per unit of the machine kilovolt-amperes and voltage, and all these multiple values may be correct when defined properly in terms of rotor-current bases.

It is general practice at the present time to derive the per-unit impedances of the various circuit elements in an individual and detached sense. For instance, an impedance measurable from the stator is converted to per unit by dividing the physical value by the selected unit value of stator ohms X_{ao} (universally taken as phase voltage divided by phase current); the per-unit impedances of the various elements in the multiple rotor circuits are obtained by transferring the corresponding physical impedances to the stator by some effective stator-rotor turn ratio, and dividing the transferred values by X_{ao}. The various rotor-circuit impedances published by any one investigator usually are consistent among themselves when studied as a detached group, but the per-unit impedances published by different investigators do not always agree when placed in apposition, because the different investigators do not necessarily select the same effective turn ratio.

Such ambiguity could be predicted by noting that the turn ratio of a synchronous machine is an elusive quantity, as there is no unique value which could be called "the" turn ratio. For instance, one turn ratio could be defined as the ratio of the series turns per stator phase to the rotor turns per pole; a second turn ratio could use the effective series turns per stator phase including the K_pK_d factor; still another ratio could use the mathematical turns per pole in the fundamental components of the stator- and rotor-excited flux waves; and there are still other turn ratios, all of which have strong physical characteristics arguing for their use. It is not surprising, therefore, that published formulas for rotor-circuit impedances are not in strict accord

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site.) The values indicated are applicable when the armature is revolving at maximum rated speed in its own bearings.

Checks on the amplitude of unbalance may be made with a simple vibrometer of the type shown in Figure 9, which consists of a dial indicator mounted in a heavy base. The heavy base provides high inertia allowing the dial-indicator case to remain substantially stationary in space while the indicator plunger is free to follow the linear motion of the bearing. Other types of simple portable indicators are available for these measurements.

Conclusions

Restoring damaged armatures to their original condition and making improvements where needed involves many factors and combinations of many arts. Some of the considerations are peculiar to the armature repairing trade, requiring the application of engineering techniques of comparable order to those used in the building of new armatures if new-armature efficiency is to be maintained.

By their omission it is not the intention to minimize the importance of other equally essential, though better publicized, factors as: Process and final testing, soldering and brazing, and record keeping.

The methods and desired results discussed are not all new, but it is hoped this paper has correlated some of the older methods and injected some new ones that will result in better armature repairing.

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Table I

e_a, e_b, e_c	in per unit of	e_{a0}
ψ_d, ψ_q	in per unit of	ψ_{a0}
i_d, i_q	in per unit of	i_{a0}
ψ_{fd}, ψ_{fq}	in per unit of	ψ_{fd0}
ψ_{nd}, ψ_{nq}	in per unit of	ψ_{nd0}
I_{fd}, I_{fq}	in per unit of	I_{fd0}
I_{nd}, I_{nq}	in per unit of	I_{nd0}

since these formulas of necessity employ some turn ratio. The question then arises as to which of these ratios is correct, or, if there is no unique correct value, which turn ratio should be used to obtain the per-unit impedances for synchronous-machine analysis; and to what degree are these various impedances affected by the turn-ratio selection.

The importance of the role played by the selected turn ratio in the magnitude of the per-unit impedances is physically self-evident, but the equal importance of the rotor-circuit current selected as unity is not so evident. By means of X_{afd}, however, it can be proved as follows that the selection of the turn ratio is tantamount to the selection of unit rotor-circuit current. X_{afd} is defined as the voltage induced in each stator phase per ampere field current, and X_{afd} is the corresponding per-unit value. As normal stator voltage is universally taken as unity, however, the product $X_{afd}I_{fd}$ must be unity at normal open-circuit air-gap-line stator voltage which shows that the unity field current I_{fd0} is not submissive to free selection after the turn ratio has been selected.

The relation which exists between the turn ratio and the unit field current suggests that these are equivalent and that rather than selecting a turn ratio it should be just as practicable to select a unit field current and have the turn ratio be derived therefrom. This is proved in the analysis of this article, not only for the field-winding circuit but for any of the rotor circuits, and, as unit rotor-circuit currents are visualized more easily than turn ratios, they are employed in the generalized impedance formula which are presented in this article.

The foregoing discussion has not answered the question as to which turn ratio should be used in the per-unit impedance formulas, but the emergence of the rotor-circuit unit currents shows that the per-unit impedances and the unit currents must be obtained simultaneously. The per-unit impedance formulas must be obtained in terms of the ampere-inch impedances and the selected unit currents. To obtain these results it is ineluctable that the synchronous-machine equations be derived first in the physical ampere-inch system and converted as a group into per-unit equations. The per-unit impedance formulas thereby obtained will then show which of the limitless series of unit currents should be used.

The method previously outlined is presented in this paper. The per-unit impedance formulas thereby obtained are given in the following section, and are in terms of the selected unit currents. The flexibility and generality of these expressions are discussed in the subsequent section, "Conclusions."

Results

Formulas for the per-unit impedances of a three-phase synchronous machine are given in the following in terms of the "ampere-inch" impedances and the "base-current ratios." The ampere-inch impedances are defined as the circuit impedances in physical units such as amperes, inches, seconds, as contrasted to the per-unit impedances which are pure numerics. The base-current ratios are defined as the ratio of the rotor-circuit currents selected as bases to $\frac{3}{2}$ the peak value of rated stator-phase currents. As previously discussed, the selection of base-current ratios is equivalent to the selection of stator-rotor turn ratios. The degree to which each impedance is dependent upon the base-current ratios is apparent from the following expressions. A consistent per-unit system with reciprocal per-unit mutual impedances will be obtained from these formulas. All terms are defined in the nomenclature.

$$x_d = \frac{L_d}{L_{a0}} \tag{1a}$$

$$x_{ad} = \frac{L_{ad}}{L_{a0}} \tag{1b}$$

$$X_{afd} = X_{fad} = \frac{3}{2}\frac{L_{afd}}{L_{a0}}\left(\frac{I_{fd0}}{\frac{3}{2}i_{a0}}\right) \tag{2a}$$

$$X_{and} = X_{nad} = \frac{3}{2}\frac{L_{and}}{L_{a0}}\left(\frac{I_{nd0}}{\frac{3}{2}i_{a0}}\right) \tag{2b}$$

$$X_{ffd} = \frac{3}{2}\frac{L_{ffd}}{L_{a0}}\left(\frac{I_{fd0}}{\frac{3}{2}i_{a0}}\right)^2 \tag{3a}$$

$$X_{nnd} = \frac{3}{2}\frac{L_{nnd}}{L_{a0}}\left(\frac{I_{nd0}}{\frac{3}{2}i_{a0}}\right)^2 \tag{3b}$$

$$X_{afd} = X_{fad} = \frac{3}{2}\frac{L_{afd}}{L_{a0}}\left(\frac{I_{fd0}\,I_{nd0}}{\frac{9}{4}i_{a0}^2}\right) \tag{3c}$$

$$X_{and} = X_{nad} = \frac{3}{2}\frac{L_{and}}{L_{a0}}\left(\frac{I_{nd0}}{\frac{3}{2}i_{a0}}\right)^2 \tag{3d}$$

$$r = \frac{r}{X_{a0}} \tag{4}$$

$$R_{ffd} = \frac{3}{2}\frac{R_{ffd}}{X_{a0}}\left(\frac{I_{fd0}}{\frac{3}{2}i_{a0}}\right)^2 \tag{5a}$$

$$R_{and} = \frac{3}{2}\frac{R_{and}}{X_{a0}}\left(\frac{I_{nd0}}{\frac{3}{2}i_{a0}}\right)^2 \tag{5b}$$

$$R_{nfd} = R_{fnd} = \frac{3}{2}\frac{R_{nfd}}{X_{a0}}\left(\frac{I_{fd0}\,I_{nd0}}{\frac{9}{4}i_{a0}^2}\right) \tag{5c}$$

$$R_{nnd} = R_{nnd} = \frac{3}{2}\frac{R_{nnd}}{X_{a0}}\left(\frac{I_{nd0}}{\frac{3}{2}i_{a0}}\right)^2 \tag{5d}$$

The per-unit values of the rotor-circuit voltages are given by the following formulas:

$$E_{fd} = \frac{E_{fd}}{e_{a0}}\left(\frac{I_{fd0}}{\frac{3}{2}i_{a0}}\right) \tag{6a}$$

$$E_{nd} = \frac{E_{nd}}{e_{a0}}\left(\frac{I_{nd0}}{\frac{3}{2}i_{a0}}\right) \tag{6b}$$

$$p = \frac{1}{\omega}p \tag{6c}$$

The direct-axis field-winding current as obtained in any per-unit system defined by the foregoing formulas will be in per unit of the selected base current I_{fd0}, but the currents of all the additional rotor circuits are expressed in per unit of the base current of the xth direct-axis additional rotor circuit, with the xth circuit submissive to free selection. When advantages are obtainable by the introduction of individual base currents for any or all of the additional rotor circuits, these new bases may be introduced by the methods originating in this article. It is evident from the foregoing formulas, however, that a change in the base currents will result in a change in the per-unit impedances.

Only the direct-axis impedances are given explicitly in the preceding formulas. The quadrature-axis impedances can be obtained from the direct-axis expressions previously given by merely replacing the *d* subscripts by *q*; this will express all the quadrature-axis currents in terms of the selected quadrature-axis base currents. It is often advantageous, however, to express the quadrature-axis currents in terms of the direct-axis bases since the latter are more easily determined: in this case, the quadrature-axis per-unit impedances are obtained from the direct-axis formulas previously given by first replacing all the *d* subscripts by *q*, and then placing the quadrature-axis current bases equal to the direct-axis bases.

Conclusions

Given in the foregoing are conversion formulas for converting ampere-inch impedances into per-unit impedances. These expressions were obtained by converting a *system* of ampere-inch equations into a *system* of per-unit equations, rather

than by deriving the per-unit impedance of each circuit element as a detached independent entity. The only condition imposed during the derivation of the conversion formulas, and it is important to note that in a per-unit system this is an externally imposed condition, was that the per-unit mutual impedances must be reciprocal.

The most important result given by the foregoing formulas is the proof that no unique value of base-current ratio is demanded by the general per-unit system. The base rotor-circuit currents are entirely submissive to free selection, conditioned only by the restriction that when any value of rotor-circuit current has been selected as a base it must be used in the calculation of the machine impedances in the consistent method defined by the foregoing formulas.

The preceding expressions definitely prove, however, that the numerical values of many of the per-unit impedances are dependent upon the value of the rotor-circuit current which has been selected as a base. It is not surprising, therefore, that different numerical values may be published for the same machine impedance, as the base currents are not necessarily equal in the various publications. Before the results of different investigations are compared, the impedances must be reduced to a common current base. This can be done by reducing the impedance expressions to forms analogous to those already given as the base-current ratios will then be identifiable.

Not all the per-unit impedances are dependent upon the base-current ratios as is shown by equations 1a, b, and 4. If the stator base is defined as rated kilovolt-amperes and rated voltage, the impedances 1a, 1b, and 4 are invariant. That these are all measurable from the stator terminals is suggestive that all such impedances measurable from the stator terminals (the definitive impedances) are similarly invariant. This is proved in Appendix I wherein the $x_d(p)$ function[1,2] —the operational machine impedance viewed from the stator—is given in terms of the foregoing conversion formulas. It is there shown that the base-current ratios may be canceled out leaving $x_d(p)$ and $x_q(p)$ as invariant impedances. Hence, all impedances measurable from the stator terminals, such as x_d, x_d' x_2, r, are independent of the values of rotor-circuit currents selected as bases. The impedances which are not invariant are those internal impedances which cannot be measured from the machine terminals.

The invariance of the definitive impedances is of great importance in system studies, and so forth, wherein only the machine terminal phenomena are desired, but, in those more general problems for whose solution the internal organization of the machine is indispensable, all the machine impedances are employed, and the base rotor-circuit currents used in the calculation of the machine impedances must be known, and the corresponding base-current ratios must be employed in the impedance calculations in the consistent method defined by the foregoing formulas.

The second and concluding part of this paper presents a review of the base-current ratios which have been used, generally implicitly, in contemporaneous technical literature and suggests the adoption of a standard or preferred rotor-circuit current as a base value so as to make various published results consonant with each other.

Derivation of Generalized Per-Unit Impedance Formulas

Ampere-Inch Linkage Equations

Using the inductance coefficients defined in the nomenclature, the stator-phase linkages due to the rotor-circuit currents in the direct and quadrature axes can be written directly as in equations 7a, b, respectively.

$$10^{-8}\psi_{as} = +(L_{afd}I_{fd} + L_{a1d}I_{1d} + L_{a2d}I_{2d} + \ldots)\cos\theta_a \quad (7a)$$

$$10^{-8}\psi_{as} = -(L_{afq}I_{fq} + L_{a1q}I_{1q} + L_{a2q}I_{2q} + \ldots)\sin\theta_a \quad (7b)$$

The corresponding linkages in the b phase and c phase may be written from equations 7a, b by replacing θ_a by θ_b and θ_c, respectively.

The stator phase linkages due to the stator currents can be written as in equation 7c. This ampere-inch expression can be derived in a manner analogous to the per-unit expression of Park.[3]

$$10^{-8}\psi_{as} = -\frac{2}{3}\left(\frac{L_d+L_q}{2}\right)\left(i_a - \frac{i_b+i_c}{2}\right) - \frac{1}{3}L_0(i_a+i_b+i_c) - \frac{2}{3}\left(\frac{L_d-L_q}{2}\right)\times(i_a\cos 2\theta_a + i_b\cos 2\theta_a + i_c\cos 2\theta_b) \quad (7c)$$

The corresponding linkages in the b phase and c phase may be obtained from equation 7c by cyclic rotation of the phase currents and phase angles.

The linkages in the direct-axis field winding due to the rotor currents in the direct-axis may be written as in equation 8a by means of the self- and mutual-inductance coefficients defined in the nomenclature.

$$10^{-8}\psi_{fd} = L_{ffd}I_{fd} + L_{f1d}I_{1d} + L_{f2d}I_{2d} + \ldots \quad (8a)$$

The corresponding equations for the linkages in the direct-axis additional rotor circuits can be written from equation 8a by analogy. The linkage equations for the quadrature-axis circuits can be written from equation 8a by substituting q for d.

In the physical ampere-inch system, all the mutual-inductance coefficients must be reciprocal. The linkages in the direct-axis and quadrature-axis field windings due to the stator currents thus may be written as in equations 8b, c directly from equations 7a, b, respectively.

$$10^{-8}\psi_{fd} = -L_{fad}(i_a\cos\theta_a + i_b\cos\theta_b + i_c\cos\theta_c) \quad (8b)$$

$$10^{-8}\psi_{fq} = +L_{faq}(i_a\sin\theta_a + i_b\sin\theta_b + i_c\sin\theta_c) \quad (8c)$$

The linkages in the additional rotor circuits can be written from equations 8b, c by analogy.

The complete stator and rotor linkages will be simplified considerably if the direct-axis and quadrature-axis linkages, defined as in equations 9a, b, are first introduced.

$$\psi_d = +\frac{2}{3}(\psi_a\cos\theta_a + \psi_b\cos\theta_b + \psi_c\cos\theta_c) \quad (9a)$$

$$\psi_q = -\frac{2}{3}(\psi_a\sin\theta_a + \psi_b\sin\theta_b + \psi_c\sin\theta_c) \quad (9b)$$

The i_d and i_q equations can be obtained from equations 9a, b by substituting i for ψ everywhere.

Introducing equations 9a, b into the preceding equations gives the complete direct-axis linkages of equations 10a, b.

$$10^{-8}\psi_d = L_{afd}I_{fd} + L_{a1d}I_{1d} + L_{a2d}I_{2d} + \ldots - L_d i_d \quad (10a)$$

$$10^{-8}\psi_{fd} = L_{ffd}I_{fd} + L_{f1d}I_{1d} + L_{f2d}I_{2d} + \ldots - \frac{3}{2}L_{fad}i_d \quad (10b)$$

The linkage equations of the direct-axis additional rotor circuits can be written from equation 10b by analogy. The complete quadrature-axis linkages can be obtained from the direct-axis linkages by substituting q for d.

Note that the mutual-inductance coefficients between the rotor and stator as obtained in equations 10a, b are no longer reciprocal because of the presence of the factor $^3/_2$. This nonreciprocity has been introduced by the definitions 9a, b, since with these definitions unit stator-phase current will give only two-thirds units of i_d or i_q.

Per-Unit Linkage Equations

A per-unit system consistent in both per-unit impedances and per-unit linkages and currents will be obtained by converting the system of ampere-inch equations represented by equation 10a, b into a corresponding per-unit system. The various quantities will be expressed in terms of the base values given in Table I.

This paper expresses all the rotor quantities in per unit of the base values of the field winding and the xth additional rotor circuit.

Only the first three base quantities in Table I are thus far specified, since these are to be taken as the values correspond-

ing to rated stator kilovolt-amperes and voltage. The base rotor quantities can be specified by introducing the following relations between the various base currents and linkages:

$$k_{sf}\psi_{ao} = 10^3 L_{afd} I_{fdo} \tag{11a}$$

$$k_{sf}\Psi_{fdo} = 10^3 L_{ffd} I_{fdo} \tag{11b}$$

$$k_{sd}\psi_{ao} = 10^3 L_{axd} I_{xdo} \tag{11c}$$

$$k_{sd}\Psi_{xdo} = 10^3 L_{xxd} I_{xdo} \tag{11d}$$

Dividing the linkage equations ψ_d, Ψ_{fd}, Ψ_{1d}, Ψ_{2d}, and so forth, by equations 11a, b, c, d, respectively, gives the per-unit equations of 12a, b, c, d.

$$\psi_d = k_{sf} I_{fd} + k_{sd} \frac{L_{axd}}{L_{xxd}} I_{1d} + k_{sd} \frac{L_{axd}}{L_{xxd}} I_{2d} + \ldots - \frac{10^3 L_{ad} i_{ao}}{\psi_{ao}} i_d \tag{12a}$$

$$\Psi_{fd} = k_{sf} I_{fd} + k_{sf} \frac{L_{ffd}}{L_{ffd}} \frac{I_{2do}}{I_{fdo}} I_{1d} + k_{sf} \frac{L_{ffd}}{L_{ffd}} \frac{I_{2do}}{I_{fdo}} I_{2d} + \ldots - \frac{1.5\times 10^3 L_{afd}}{\Psi_{fdo}} i_{ao} i_d \tag{12b}$$

$$\Psi_{1d} = k_{sd} \frac{L_{1fd}}{L_{2xd}} \frac{I_{fdo}}{I_{2do}} I_{fd} + k_{sd} I_{1d} + k_{sd} \frac{L_{12d}}{L_{2xd}} I_{2d} + \ldots - \frac{1.5\times 10^3 L_{a1d}}{\Psi_{2do}} i_{ao} i_q \tag{12c}$$

$$\Psi_{2d} = k_{sd} \frac{L_{1fd}}{L_{2xd}} \frac{I_{fdo}}{I_{2do}} I_{fd} + k_{sd} \frac{L_{12d}}{L_{2xd}} I_{1d} + k_{sd} \frac{L_{12d}}{L_{2xd}} I_{2d} + \ldots - \frac{1.5\times 10^3 L_{a2d}}{\Psi_{2do}} i_{ao} i_q \tag{12d}$$

In order that the per-unit equations should retain the physical features of the ampere-inch system and not degenerate into an array of mathematical expressions, the per-unit mutual-inductance coefficients must be made reciprocal. Note that this is an applied condition which removes the nonreciprocity introduced by the definitions 9a, b. The k quantities accordingly must satisfy the relations given by equations 13a, b, c.

$$k_{sf} = \frac{1.5\times 10^3 L_{afd}}{\Psi_{fdo}} i_{ao} \tag{13a}$$

$$k_{sd} = \frac{1.5\times 10^3 L_{axd}}{\Psi_{xdo}} i_{ao} \tag{13b}$$

$$k_{sf} \frac{L_{f1d}}{L_{ffd}} \frac{I_{2do}}{I_{fdo}} = k_{sd} \frac{L_{1fd}}{L_{2xd}} I_{fdo} \tag{13c}$$

Eliminating between equations 11a, b, c, d and 13a, b, c, d results in the following explicit expressions for the k quantities:

$$k_{sf} = \frac{3}{2} \frac{L_{afd}}{L_{ao}} \left(\frac{I_{fdo}}{\frac{3}{2} i_{ao}} \right) \tag{14a}$$

$$k_{sd} = \frac{3}{2} \frac{L_{axd}}{L_{ao}} \left(\frac{I_{xdo}}{\frac{3}{2} i_{ao}} \right) \tag{14b}$$

$$k_{sf} = \frac{3}{2} \frac{L_{ffd}}{L_{ao}} \left(\frac{I_{fdo}}{\frac{3}{2} i_{ao}} \right)^2 \tag{14c}$$

$$k_{sd} = \frac{3}{2} \frac{L_{xxd}}{L_{ao}} \left(\frac{I_{xdo}}{\frac{3}{2} i_{ao}} \right)^2 \tag{14d}$$

$$\frac{\psi_{ao}}{\Psi_{fdo}} = \frac{I_{fdo}}{\frac{3}{2} i_{ao}} \tag{15a}$$

$$\frac{\psi_{ao}}{\Psi_{xdo}} = \frac{I_{xdo}}{\frac{3}{2} i_{ao}} \tag{15b}$$

Substituting equations 14a, b, c, d into equations 12a, b, c, d results in the system of per-unit equations of 16a, b, c, d with the per-unit impedances given by the generalized formulas of 1a, b, 2a, b, and 3a, b, c, d. The impedances also may be written in terms of base linkages rather than base currents by means of equations 15a, b.

$$\psi_d = X_{afd} I_{fd} + X_{a1d} I_{1d} + X_{a2d} I_{2d} + \ldots - x_d i_d \tag{16a}$$

$$\Psi_{fd} = X_{ffd} I_{fd} + X_{f1d} I_{1d} + X_{f2d} I_{2d} + \ldots - X_{fad} i_d \tag{16b}$$

$$\Psi_{1d} = X_{1fd} I_{fd} + X_{11d} I_{1d} + X_{12d} I_{2d} + \ldots - X_{1ad} i_d \tag{16c}$$

$$\Psi_{2d} = X_{2fd} I_{fd} + X_{21d} I_{1d} + X_{2ad} I_{2d} + \ldots - X_{2ad} i_d \tag{16d}$$

The quadrature-axis equations can be obtained from equations 16a, b, c, d by substituting q for d. The foregoing equations may be reduced to those of Park[1] by the methods of reference 4.

Ampere-Inch Rotor-Circuit Voltage Equations

Conversion formulas for the rotor-circuit resistances and voltages are obtained from the rotor-circuit voltage equations. These are given in the ampere-inch system by equation 17 and are converted to per-unit in the following section.

$$E_{fd} = 10^{-3} p\Psi_{fd} + R_{ffd} I_{fd} + R_{f1d} I_{1d} + R_{f2d} I_{2d} + \ldots \tag{17}$$

The equations for E_{1d}, E_{2d}, and so forth, can be written from equation 17 by analogy. The quadrature-axis equations can be obtained from equation 17 by substituting q for d.

Per-Unit Rotor-Circuit Voltage Equations

The rotor-circuit voltage equations are converted to per-unit equations by dividing the equation for E_{fd} by Ψ_{fdo}, and by dividing the analogous equations for E_{1d}, E_{2d}, and so forth, by Ψ_{xdo}. The system of per-unit equations thereby obtained is given by equations 18a, b, c.

$$\frac{E_{fd}}{\Psi_{fdo}} = 10^{-3} p\Psi_{fd} + \frac{R_{ffd} I_{fdo}}{\Psi_{fdo}} I_{fd} + \frac{R_{f1d} I_{2do}}{\Psi_{fdo}} I_{1d} + \frac{R_{f1d} I_{2do}}{\Psi_{fdo}} I_{2d} + \ldots \tag{18a}$$

$$\frac{E_{1d}}{\Psi_{2do}} = 10^{-3} p\Psi_{1d} + \frac{R_{1fd} I_{fdo}}{\Psi_{2do}} I_{fd} + \frac{R_{11d} I_{2do}}{\Psi_{2do}} I_{1d} + \frac{R_{11d} I_{2do}}{\Psi_{2do}} I_{2d} + \ldots \tag{18b}$$

$$\frac{E_{2d}}{\Psi_{2do}} = 10^{-3} p\Psi_{2d} + \frac{R_{2fd} I_{fdo}}{\Psi_{2do}} I_{fd} + \frac{R_{21d} I_{2do}}{\Psi_{2do}} I_{1d} + \frac{R_{22d} I_{2do}}{\Psi_{2do}} I_{2d} + \ldots \tag{18c}$$

Introducing equations 15a, b into equations 18a, b, c will give the per-unit equations 19a, b, c with the per-unit resistances defined by the generalized formulas of 5a, b, c, d, and with the per-unit rotor-circuit voltages given by the generalized formulas 6a, b. The per-unit differential operator is given by equation 20.

$$E_{fd} = p\Psi_{fd} + R_{ffd} I_{fd} + R_{f1d} I_{1d} + R_{f2d} I_{2d} + \ldots \tag{19a}$$

$$E_{1d} = p\Psi_{1d} + R_{1fd} I_{fd} + R_{11d} I_{1d} + R_{12d} I_{2d} + \ldots \tag{19b}$$

$$E_{2d} = p\Psi_{2d} + R_{2fd} I_{fd} + R_{21d} I_{1d} + R_{22d} I_{2d} + \ldots \tag{19c}$$

$$p = \frac{1}{\omega} p = \frac{1}{\omega} \frac{d}{dt} = \frac{d}{d(\omega t)} \tag{20}$$

Nomenclature

The quantities given in the following are per-unit values (unless in bold-face type) in a consistent per-unit system with reciprocal mutual impedances. The bold-face characters used throughout the text are defined as given in the following but are in the "ampere-inch" system.

The ampere-inch system is defined as the system in which all quantities are expressed in their physical dimensions, such as amperes, inches, seconds. Impedances such as R and L must be calculated initially in the ampere-inch system before a per-unit value can be obtained.

The rotor circuits are separated into the main field-winding circuits and the "additional" rotor circuits. The additional rotor circuits comprise all the rotor circuits except the main field winding.

Subscript Notation

The subscript notation is as follows:

a, b, c = armature phases
f = field-winding circuit
m, n, x = additional rotor circuits
$d, q, 0$ = direct, quadrature, and "zero" axes
o = base quantities

The quantities L, R, and X use a triple subscript notation in which the first two subscripts refer to the circuits in which these impedances act, and the third subscript locates the (d or q) axis.

Application of Quality Control to Resistance Welding

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Synopsis: This paper describes a system of quality control of resistance welding that has been used successfully for the past few years in manufacturing switchgear cubicles and equipment. Standard samples of material identical with production parts are periodically inserted in the welding machine and welded without disturbing the settings and then tested to destruction in a torsion device. The diameter, torque, and angle of twist at failure all are measured and combined into a single figure indicative of weld quality. This number is plotted on control charts, and corrective action is taken whenever the control limits are exceeded. By setting these limits well within allowable values the quality of production parts is assured.

QUALITY CONTROL of resistance welding, in shops handling a large variety of work, has been simply and effectively accomplished. The methods of testing and control give assurance of uniform weld quality on a process where visual inspection leaves considerable to be desired, making possible the use of resistance welding on assemblies where high quality must be maintained at all times.

Standardization of the welding procedure is essential to the statistical control of the process. Suitable tables, giving the proper settings of the welding-machine controls, must be available to operators so that adjustments can be made to secure the best possible results for the conditions of each job. These settings are too important to be determined by any approximate methods. It is, likewise, essential that the equipment itself and its controls be adequately maintained to insure that, at a given setting, welds of uniform quality are produced. An adequate supply of electric power is necessary to insure consistent performance.

The quality-control procedure described in this article was developed over a considerable period of time. This report will give a brief picture of the method and its application. The mathematical details involved in the development of the quality index and statistical-control limits are not intended to be within the scope of this paper.

The structural stability of assemblies which are made with the use of resistance welding depends chiefly upon:

1. The quality of the parts used.
2. The quality of the welded section.

The quality of the parts used is controlled easily by usual methods of inspection and quality control. Attention, therefore, is directed entirely to the quality of the welded joints. Primarily, we are interested in the strength and ductility of the welds—the two things which are most difficult to determine without destruction of the fabricated parts. We also are interested in the appearance of the weld, the proper dimensions of the welded assemblies, and the change in dimensions caused

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e_a, e_b, e_c = stator-phase voltages, peak values
e_{ao} = peak value of rated stator-phase voltage
E_{fd} = field-winding circuit voltage
E_{nd} = voltage in nth additional rotor circuit
i_a, i_b, i_c = stator line currents, peak values
i_{ao} = peak value of rated stator line current
i_d, i_q, i_0 = stator current in d, q, and O axes, respectively
I_{fd}, I_{fq} = current in field-winding circuits
I_{fdo} = base value of field current
I_{nd}, I_{nq} = current in nth additional rotor circuits
I_{ndo} = base value of current in additional rotor circuits
L = mutual inductance between the circuits specified by the first two subscripts
L_{ao} = base (stator) inductance = $\frac{10^{-5}\psi_{ao}}{i_{ao}} = \frac{X_{ao}}{\omega}$
L_{ad}, L_{aq} = inductance of armature reaction with the stator magnetomotive force in the direct and quadrature axes, respectively
L_d, L_q, L_0 = synchronous inductance; direct, quadrature and zero axes, respectively
p, ρ = differential operator $\frac{d}{dt}$, $\frac{d}{d(\omega t)}$ respectively
r = stator resistance per phase
R = mutual resistance between the circuits specified by the first two subscripts
X = mutual reactance between the circuits specified by the first two subscripts
X_{ao} = base reactance = ωL_{ao}
x_{ad}, x_{aq} = reactance of armature reaction
x_d, x_q = synchronous reactance
x_2 = negative-sequence reactance
$x_d(\rho)$ = operational impedance viewed from stator terminals
θ_a, θ_b, θ_c = angle between center-line of direct-axis (main pole) and center line of stator phase indicated by subscript
ψ_a, ψ_b, ψ_c = stator phase flux linkages, peak values
ψ_{ao} = peak value of rated stator-phase linkages
ψ_d, ψ_q = stator linkages in d and q axes, respectively
Ψ_{fd}, Ψ_{fq} = linkages in field-winding circuits
Ψ_{nd}, Ψ_{nq} = linkages in nth additional rotor circuits
$\omega = 2\pi$ times frequency

Appendix. The $x_d(p)$ and $x_q(p)$ Functions

The $x_d(\rho)$ function is defined as the operational impedance as viewed from the stator terminals. In a general per-unit system, the $x_d(\rho)$ of a machine with only one additional rotor circuit in the direct axis is as given by equation 21a.[2]

$$x_d(\rho) = x_d - \frac{\left[\rho^3(X_{11d}X_{afd}{}^2 - 2X_{f1d}X_{a1d}X_{afd} + X_{ffd}X_{a1d}{}^2) + \rho(X_{afd}{}^2R_{11d} + X_{a1d}{}^2R_{ffd})\right]}{\left[\rho^2(X_{11d}X_{ffd} - X_{f1d}{}^2) + R_{11d}R_{ffd} + \rho(X_{11d}R_{ffd} + X_{ffd}R_{11d})\right]} \quad (21a)$$

Substituting the per-unit formulas given under "Results" into equation 21a gives $x_d(\rho)$ in terms of the ampere-inch impedances as in equation 21b.

$$x_d(\rho) = \frac{L_d}{L_{ao}} - \frac{1.5}{L_{ao}} \times \frac{\left[\rho^3(L_{11d}L_{afd}{}^2 - 2L_{1fd}L_{a1d}L_{afd} + L_{ffd}L_{a1d}{}^2) + \rho(L_{afd}{}^2R_{11d} + L_{a1d}{}^2R_{ffd})\right]}{\left[\rho^2(L_{11d}L_{ffd} - L_{1fd}{}^2) + R_{11d}R_{ffd} + \rho(L_{11d}R_{ffd} + L_{ffd}R_{11d})\right]} \quad (21b)$$

Since equation 21b is independent of any base-current ratios $x_d(\rho)$, is invariant when expressed in per unit of the machine kilovolt-amperes and voltage, and is independent of the base rotor-circuit currents; $x_q(\rho)$ is similarly invariant. The foregoing proof can be extended to include any number of additional rotor circuits.

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by the welding. These can be determined easily by visual inspection and measurement.

In determining the best method for testing the strength and ductility of resistance welds where it is not practical to test to destruction, we have chosen to make test specimens of material identical in quality and thickness to the regular production parts but of a suitable size for testing. These samples are made with the machine settings identical to those under which the production work is being done. These samples are made at frequent intervals to insure that the quality of the welds made by the machine is maintained at the required quality level. From the results of the tests, a quality-control index is determined, and the average value is charted to give a continuous record of performance.

On highly repetitive jobs it is only necessary to establish the proper welding procedure once and then continue on that basis for the duration of the job. However, when the welding conditions are variable, as in the case of fabrication of switchgear equipment, it is necessary to have a specific procedure for each combination of materials. Figure 1 is an example of a cubicle frame showing the many combinations of materials that may be encountered in this type of structure.

In the absence of basic fundamental data for such conditions, it was necessary to undertake an extensive program to determine the effects of the several variables, such as: material type and thickness; welding current, pressure, and time; proximity of adjacent welds; and overlap.

Many thousands of tests were made on weld specimens in which these factors were independently varied. From this study it was possible to establish the proper welding procedures and the physical properties of the welds. This information was given to both the engineering and the manufacturing sections and is prominently posted on each welding machine.

With a standardized welding procedure, it is obviously necessary to have properly calibrated reliable welding machines. Our machines are equipped with thyratron synchronous controls to assure that, once the machine has been set for a definite procedure, all of the welds made will be consistent. Figure 2 shows a typical machine. Note that the adjusters for the thyratron control panel, the current regulator, the sequence panel, and the air circuit breaker, as well as the pointer stop ammeter and pressure gauge, are conveniently located on the front of the machine, readily accessible to the operator.

By means of plug-in jacks, the calibrations of the machines are checked at regular intervals; thus, it is necessary only for the operator to set the controls, using the applicable welding procedure.

Once the machine has been adjusted, good consistent welds should be obtained. However, it is necessary to check the results periodically to guard against carelessness on the part of the operator, improper functioning of the welding machine, or inconsistencies in the parts.

The quality of a resistance weld is dependent largely upon three factors: appearance, strength, and ductility; and it is these factors which the quality-control system must control. The necessity for maintaining the appearance of the welds is obvious. This factor is controlled by measuring the tip indentation on spot welds and by comparing with visual

Figure 1 (left). Switchgear cubicle fabricated by spot welding—rear view

Figure 2 (below left). Control apparatus for resistance-welding machine

Figure 3 (below right). Resistance-spot-welded test specimen being placed in testing machine

standards. The strength of the weld is essential as the design of the structure is based on the established minimum weld strength. The ductility of a weld is essential as it is an indication of the resistance to shock and fatigue strength.

At the present time no method has been found to determine the ultimate strength

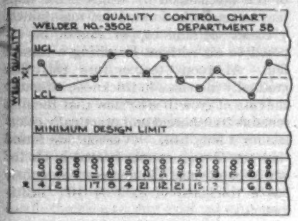

Figure 4. Control chart

and ductility of a weld except by a destructive test.

In the investigation undertaken to determine the optimum welding procedures, it was found that the most satisfactory method of test for spot welds on heavy steels (one-eighth inch thick and over) was torsional testing. A special machine for this purpose was designed and built in the Philadelphia works laboratory of the General Electric Company. This machine subjects the weld to torsional shear about the center of the weld, and the ultimate torque and angle of twist at the ultimate torque are measured. Figure 3 shows one of the torsional testing machines now being used by the inspection and quality-control division. This torsional testing gives a simple and accurate means of determining the weld strength and ductility, since the strength is proportional to the ultimate torque and the weld diameter (which is easily measured). The ductility is proportional to the angle of twist.

These factors are combined to give a quality-control number which is an index of the quality of the weld. By the use of this comparative index in statistical control, it is possible to show the changes in process performance.

Because of limitations in the skill and ability of the control operators available for this work and the necessity of limiting the time required for testing, a simple, quick, and effective control method is essential to the success of this program.

The control-chart method of controlling quality as covered by the American Standards Association publications Z1.1, Z1.2, and Z1.3 was adopted for this work using a chart for averages ($\bar{X}$) with a modified range (R) chart. After a few weeks of trial testing, during which the process was checked for control by a study of the frequency-distribution charts on data collected, it was found that a sample lot of three would be adequate for control of this process. Control limits were established for the grades of steels in common use. Control-chart scales were developed

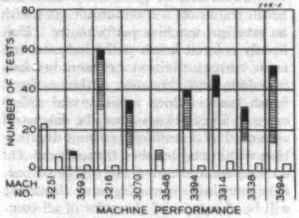

Figure 5. Weekly machine performance

for each grade of steel so that one set of control limits would be common for all combinations of materials. This simplified the control chart and made possible a form of report which is a composite picture of the quality level being maintained in an operating division on all spot welding, regardless of how diversified the work.

The control-chart scales are so proportioned that all limit lines coincide with common lines on the chart, with the distance from the central line to the upper and lower limits divided into a suitable number of equal divisions. The scale distance from the lower control line to the minimum design-limit line and the distance from the upper control line to the upper limit of the chart are similarly divided. Averages below ten are plotted as zero and averages above 60 are plotted as 60. Distribution diagrams for the various grades of steels thus will be shown in proper relationship to the limit lines on the chart, and the composite diagram will be an indication of the over-all control of the process.

The weld test specimens are made from drop-off pieces of materials currently being used in the shop. A supply of these samples is kept in suitable containers in the welding areas. A test is taken on each welder in operation once each hour. Three samples of the same combination of materials and thicknesses are welded under the same conditions of machine control setting being used on the production work at the time of test. No adjustment of the machine is permitted at the time of test, as control is based upon machine performance under production conditions.

Control charts shown in Figure 4 are placed on each machine, and the results of

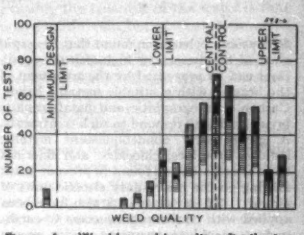

Figure 6. Weekly weld-quality distribution

tests are posted after each test. A record sheet is filled in by the control operator and becomes a permanent record of performance in the welding sections. The machine chart is forwarded to the foreman's office the following morning, and the record sheet is forwarded to the central control office for analysis.

The daily records are posted on a weekly record sheet in convenient form to show the frequency-distribution totals for all welding combinations based on machine and process performance. When completed, this record sheet contains complete information for the weekly report which is distributed to the department heads, manufacturing superintendents, welding engineers, quality-control specialists, and inspection supervisors.

The weekly report gives a complete analysis of weld quality control by showing the relative performance for each machine in the section, Figure 5, and frequency-distribution diagrams, Figure 6, showing the relative effect of materials and welding methods on the over-all level of weld quality.

This method of controlling weld quality has given excellent results. Proof tests on welded structures made under controlled conditions have proved the effectiveness of the control. Special test structures have been made and subjected to severe shock conditions without any weld failures. Resistance welding, properly controlled, becomes a safe dependable fabrication process. Quality control of this process can insure strong dependable welds of uniformly high quality.

Treatment of High-Altitude Brushes by Application of Metallic Halides

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Synopsis: It has been found that the rapid wear of brushes under high-altitude conditions can be prevented by the treatment of the brushes with a suitable metallic halide. Carbon, electrographitic, and metal-graphite brush grades all respond to such treatments. A great many nondeliquescent metallic iodides, bromides, chlorides, and fluorides have been tested and found to prevent brush dusting on the heavy-duty electric units of aircraft. These treatments also have been applied with considerable success to earth-surface machines operating under severe commutating conditions. A mechanism by which this class of chemical compound may react to maintain a satisfactory low-friction film on a commutator is proposed.

IT IS BELIEVED that the manufacturers and operators of commutating electric machines and the producers of brushes for them are in complete agreement on only two points:

1. They agree that a film on the commutator is essential for long brush life.

2. The film on a commutator should be as uniform as possible on the entire commutator surface if optimum commutation is desired.

The precise chemical nature of this essential film is still a subject of discussion. The mechanism of its formation is also not certain. The film is extremely thin, and its weight per unit area is so small that an accurate chemical analysis is difficult. Recently Van Brunt and Savage[1] reported a typical film to consist largely of cuprous oxide and carbon (with a number of minor ingredients totaling only 12 per cent). They calculated the film thickness as 5.4×10^{-6} centimeters of which 2.1×10^{-6} centimeters was copper oxide. These workers and many others stress the complex composition of commutator films. It is the thesis of the present paper that an *ideal* commutator film is composed substantially of cuprous oxide (the oxide of monovalent copper) and that all other substances which are present in *actual* films are either nonessential or are definitely harmful.

The color of the track produced on a copper commutator by a given brush grade is a measure of the thickness of the commutator film. This thin protective nonmetallic layer holds the brushes from direct contact with the metal and thus prevents rapid wear. This film should develop to a uniform thickness under all brushes if they are all alike and if the operating conditions are the same for all brushes. Experience has shown that a high uniformity in the color of all of the brush tracks on a commutator goes with an excellent machine performance. Uniformly colored brush paths indicate uniform current division between brushes. Streaking and threading within a single brush track (which again reveal differences in film thickness) may be diagnosed as caused by nonuniform current distribution within the brushes themselves. On an *ideal* commutator there will be no bar-edge burning; streaking and threading will be absent; and the color of all commutator bars will be exactly the same.

An *actual* commutator never meets these desired standards of uniformity. The brush tracks are never exactly alike in color, and a critical eye can always detect some evidence of streaking, no matter how slight. Though an electrographitic brush is expected to develop a rich satiny chocolate-brown polish on the copper, there is wide disagreement as to the depth or shade of color which is most desirable.

Figure 1. Copper slip rings and brushes after test in high-altitude test chamber

Early in World War II it was reported that brushes wore rapidly at times on certain airplane equipment when they were operated at altitudes above 20,000 feet. Apparently the commutator film, normally maintained at low altitudes, might disappear quite suddenly at high altitudes, and rapid brush wear, or brush dusting, then would follow through abrasion.

A discussion of this failure of commutator films under the abnormal atmospheric conditions prevailing at high altitudes is best prefaced by a consideration of the mechanism by which these films may normally be formed and maintained.

Clean metallic copper cannot be exposed to air without acquiring a tarnish film. At room temperature this film gradually increases in thickness, although the rate of growth is so slow that the film remains transparent and practically colorless for a long time. (Vernon[2] has found that the film on copper heated in air for one hour at only 130 degrees Fahrenheit has a thickness of 1.05×10^{-7} centimeters.)

The commutator is "turned to size" as one of the final steps in the manufacture of an armature. During this turning operation the copper is heated by the work done upon it. As copper is oxidized more rapidly at higher temperatures, each spot of the metal, as it emerges from under the turning tool, acquires a thicker film than it would get if it had been exposed at room temperature. In addition this initial film is further thickened during the seating of the brushes. The coefficient of friction between unseated brushes and a copper commutator is normally high. As the brushes are worn to a seat under light electric loads, their faces become polished. At the same time the film upon the commutator increases in thickness as its surface is burnished by the mechanically loaded brushes under which it moves. If the brushes have been properly chosen, if the machine is well designed, and if the running-in conditions are correct, the film will gradually increase in color, thickness, and polish, and the friction between brushes and commutator will gradually decrease.

However, the formation of a commutator film by electrically loaded brushes is a relatively complex dynamic process and is by no means so simple as the description in the preceding paragraph might indicate. The heat appearing at the brush-commutator interface is generated not only by friction but also by the electric energy dissipated at this interface. (The coefficient of friction between a high-grade well-seated electrographitic brush and the burnished copper-oxide commutator film is often two tenths or higher. The double contact drop for this same type of brush will range from 1½ to 3 volts. The actual value for each of these properties will vary with the electric load, the brush grade, and the condition of the commutator.) At any given instant the electron transfer between the commutator and a brush takes place only at a few highly localized areas on the brush face. When the electric load is

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added to the already present mechanical load these spots become very hot. These overheated active areas of the brush being in close contact with the commutator will react chemically with the copper-oxide film to form metallic copper and carbon monoxide. Thus the electron transfer areas on a brush face become chemically reducing agents and defilming rather than filming agents.

When one of the minute areas of freshly reduced metallic copper emerges out from under the brush and contacts the air, it immediately is reoxidized. But as this same area soon passes under another brush, it may perhaps be reduced again before the oxide film has been re-established to normal thickness. However, under normal operating conditions at any given instant the active electron transfer area is small; thence a freshly oxidized spot may pass under several brushes without again being reduced, thus allowing the film to be built up to equilibrium thickness during the repeated periods of air exposure. Nevertheless, with continued operation, an area on a commutator is frequently reduced and again reoxidized. Therefore the oxide film should be regarded as dynamic rather than static.

The character of the cuprous-oxide film on a commutator will depend on many variables: the properties of the brushes, the shape of their faces, the angle at which they contact the commutator, the spring loading placed upon them, the area of the commutator covered by them, their operating temperature, the temperature of the commutator, and the purity of the ventilating air all play essential roles in controlling the thickness and quality of the film which is developed. The film, as previously explained, is a dynamic, alterable structure. It is possible that a slight change in operating conditions will alter it drastically overnight. A seemingly insignificant change in the surroundings may affect it; for example, a shift in the wind direction may bring a trace of hydrogen sulphide into the room. A leaking gas tunnel has also been responsible for the malperformance of a group of machines in a steel mill. The edges of the commutator in such contaminated atmospheres became covered with a continuous gray film of copper sulphide, and the brush tracks were blotched with irregular patches of this compound scattered in between the normal cuprous-oxide areas. Copper sulphide may completely replace cuprous oxide as a commutator film, if the hydrogen sulphide in the air reaches the concentrations sometimes found in a kraft paper mill. Brush wear is always excessive under such conditions. Generally it can be said that anything will impair the performance of a machine and affect brush wear which alters the ability of the air to oxidize copper and thus maintain a continuous well-polished cuprous-oxide film on its commutator.

It is well known that the surface of a piece of copper, which initially had a high polish, will be roughened by exposing it to repeated oxidation and reduction. However, continued operation of a commutator under ideal operating conditions increases rather than diminishes the finish of the surface. It is believed that a properly chosen brush polishes the oxide film as it is formed and prevents the roughening which otherwise would follow as a result of the repeated oxidation and reduction. Thus the *ideal* brush is an excellent burnishing tool: it "flows" rather than abrades the commutator film. *Actual* brushes, however, to a greater or lesser degree, fail to maintain a burnished continuous layer of cuprous oxide which is substantially free of other materials. Frequently the film becomes very rough in service and so nonuniform in its composition and properties that cleaner brushes are added to remove this undesirable film. Or, as a last resort, the commutator may be "re-turned" and the

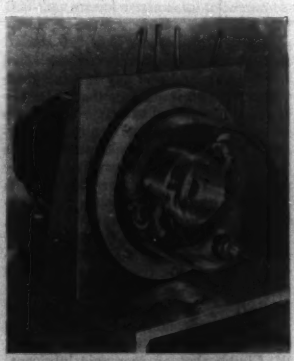

Figure 2. A simple high-altitude test chamber for testing slip rings

development of a new film attempted, probably with the aid of another brush grade.

In view of the foregoing discussion it can be easily understood why the heavy-duty airplane generators present such a difficult problem to the designer. As these generators must be as light as possible, their commutators and brushes have to be loaded to the limit. Heavily loaded commutators retain an oxide film only with difficulty even in ground service or in low-altitude flying. If the bombers are flown to an altitude of 33,000 feet, where the oxygen content of the air is approximately one fourth of that on the earth's surface, the commutator film naturally will not be maintained.

Lack of the active oxidizing agent, however, is not the only cause for the loss of the essential cuprous-oxide film in high-altitude flying. The water content of the rarefied air, is only one-thousandth that normally fed to electric machines. The extreme dryness of the ventilating air is a major cause of the disappearance of the film. The beneficial effects of water vapor usually are ascribed to lubrication of the brush-commutator interface by water vapor adsorbed in the film or brush. Possibly the true role of the water is that not of a lubricant but of a catalytic agent promoting the oxidation of copper by the oxygen of the air. As soon as the film on the commutator disappears, the brushes and copper grind one another away in a very short time.

Figure 1 shows two copper slip rings and brushes tested in our laboratory high-altitude tester. Both sets of brushes were seated on the rings while these were running in normal laboratory air. At the end of the seating period, the air was changed to simulate the pressure and dryness of the atmosphere at an altitude of 40,000 feet. After 15 minutes of operation, under electric load, one pair of brushes wore out. The faces of the brushes and their path on the copper ring were badly roughened. The second pair of brushes, tested under the same conditions for a testing time of seven hours, showed no measurable wear. The polish of the brush faces and of the brush track was unchanged. The first pair of brushes were of high-quality electrographitic material which has given excellent performance on electric machines under normal service. The second pair of brushes were from the same stock but had been treated for high-altitude operating conditions.

Epidemics of rapid brush wear occur frequently on ground-operated machines also. Such epidemics often, if not always, are associated with an unusually low water concentration in the air. The trouble often is avoided by feeding steam into the air of a generator room during extremely cold weather. However, if high-speed exciter brushes suddenly disappear in a central station, although repercussions may be heard in the front office, a standby unit usually can be thrown on the line. Or, if the brushes chatter and disintegrate on the motors of a 90-mile-an-hour locomotive during subzeor weather, while the passengers may miss engagements, they still stay alive. But if the brushes on the fully loaded generators of a fighting bomber wear out, and the turrets cannot revolve and a dozen other units fail to function, the crew on that bomber may not survive.

When rapid brush wear was shown to be a real hazard to high-altitude flying, means to combat it were sought in many places. To study brushes under simulated high-altitude conditions it was necessary to design suitable testing equipment. A simple slip-ring tester is pictured in Figure 2 and diagrammed in Figure 3. Several of these "testing chambers" have been in constant use for several years in testing hundreds of

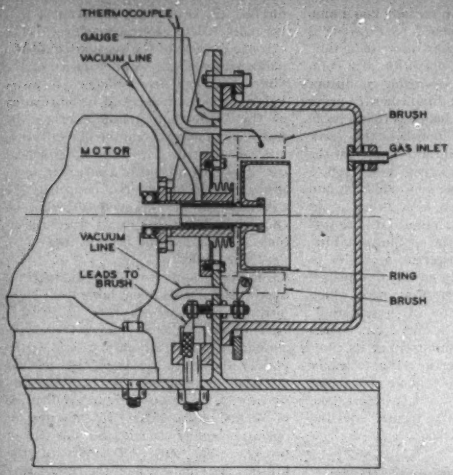

Figure 3. Cross section of test chamber shown in Figure 2

brushes. The tester consists of a copper slip ring 3¼ inches in diameter which is mounted on the shaft extension of a 3,500-rpm motor. This shaft enters the glass chamber through a close-fitting carbon tube. This tube is separately evacuated to a pressure low enough to prevent room air entering the chamber along the shaft. The pressure in the testing chamber is maintained at the desired "test altitude" while dry air is passed through to sweep out the impurities. With this tester the brushes can be operated under any mechanical or electric load throughout a wide range: the angle of the brushes can be changed, and the positive and negative brushes can run on the same or separate paths. The temperatures of the brushes and the double contact drop are recorded continuously. This tester has proved extremely useful and very reliable: it has the added advantage over most laboratory dusting testers that it gives results on the pessimistic rather than on the optimistic side.

This tester aided greatly in the search for a brush grade which would maintain a film on the commutator under all service conditions. It soon was found that for each brush grade there was a correlation between the "test altitude," the electric load, and the dusting tendency. A certain brush grade was giving long life in actual flight test. It was possible to predict on the basis of the evidence in Figure 4 that a moderate increase in the electric load in flight would cause this brush to fail. This prediction soon was verified when further flights proved that a load of 50 amperes or more would wear out in three hours the same brushes which promised a life of several hundred hours when the load was limited to 35 amperes or less.

Tests of a large number of untreated brushes failed to find any existing grade which would not dust in the laboratory tester. Therefore as the next step attention was turned to brushes impregnated with various organic compounds as lubricants. The use of paraffin and other waxes in brushes to lower their friction against copper is well known. Unfortunately, all of the organic treatments, which seem to behave as lubricants, were ineffective for this purpose as they are too volatile to stay in the brushes for more than a few hours when subjected to heavy loading.

After organic lubricants had failed to solve this problem, it was suggested by L. W. Chubb that an inorganic lubricant, molybdenum sulphide, be tried. This compound is stable, has a low vapor pressure at moderately high temperatures, and has been applied successfully as a solid lubricant in a number of specialized fields. It resembles graphite and certain other solids in having crystals of layer lattice structure.

Brushes treated with molybdenum sulphide failed to develop a characteristic dark cuprous-oxide film but transferred a thin film of a sulphide itself to the commutator. This acted as a protective lubricating film which was held tenaciously by the copper, and generators equipped with molybdenum-sulphide-treated brushes have shown low brush wear on high-altitude flights. However, sooner or later the sparking which is always present under the face of a brush, even when commutation is apparently black, must convert some of the molybdenum sulphide to molybdenum carbide. The latter is very hard and causes severe grooving of the commutator.

We arrived at the conclusion that a solid film having lubricating properties would be helpful. In accordance with this theory much thought was given to providing these solid lubricating films on commutators. It occurred to us to try lead iodide. This experiment yielded wholly unexpected and gratifying results. From previous experience it was expected that this soft yellow solid would behave like molybdenum sulphide by coating the copper with an adhering lubricating film. However, much to our surprise this did not happen. Instead the lead-iodide-treated brushes developed a characteristic dark satiny film that seemed identical with the normal cuprous-oxide film. This film then became burnished as it passed successively under the brushes and stayed on the surface even in air of low oxygen and water-vapor content. It was found that lead-iodide-treated brushes are able to maintain a perfect film even in the most adverse conditions. This we presume is made possible by the formation of an intermediate compound, cuprous iodide, which being extremely unstable is readily oxidized to cuprous oxide even in an atmosphere where the normal oxidation of copper would not take place.

If this explanation is correct, the rate at which a copper commutator can be oxidized has been increased greatly, even in air of low oxygen content and with almost no water-vapor content. After the favorable results obtained with lead iodide, it seemed reasonable to suppose that other iodides which do not have layer-lattice structure and which are not solid lubricants also should aid in the maintenance of an oxide film and thus prevent brush dusting. Actually many iodides have been tested in the laboratory and have been found to be effective.

An even more convincing evidence for the effectiveness of iodine compounds is the prevention of dusting by only a trace of iodine vapor. Under simulated-high-altitude conditions, untreated brushes, which dusted in the absence of iodine, showed low wear and developed an oxide film on a copper ring when iodine vapor was introduced.

As bromine vapor also prevents brush dusting, studies were extended to cover all metallic halides as a class. Tests were made of typical iodides, bromides, chlorides, and fluorides, and all were found effective. It is believed that each of them thermally decomposes at the brush-commutator interface to form the corresponding metal and free halogen. The latter may recombine, either with its original metallic partner, or with the carbon of the brush, or with a bare copper spot on the commutator.

However, the copper halides differ greatly in their thermal stability, the iodide being the least stable and the fluoride the most stable compound. The comparatively high stability of copper fluoride should slow down the rate at which it is oxidized. Under operating

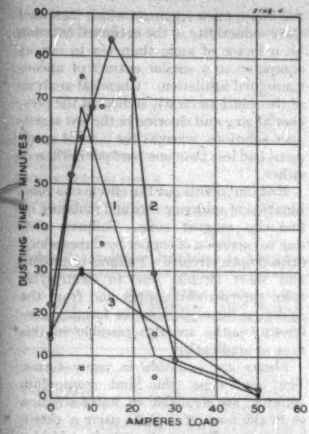

Figure 4. Amperes of load versus dusting time for an untreated hard carbon brush

Curve 1 at pressure equivalent to 30,000 feet; curve 2 at 35,000 feet; curve 3 at 40,000 feet. This brush does not dust at 25,000 feet

conditions this might lead to the existence of a film that contains substantial amounts of both the oxide and the fluoride of copper. It is therefore preferable to choose a treatment that, under the given operating conditions, develops a film substantially free of any compound other than cuprous oxide.

All of the metallic halides which have been tested as brush treatments are capable of limiting brush dusting under simulated-high-altitude conditions. Those selected for actual flight test have effectively limited brush wear. However, there are many practical difficulties in the use of many of these compounds. For example, certain halides, which are water soluble, but not deliquescent, and which contain no water of crystallization, can be put in the brushes from a water solution. However, these water-soluble halides accidentally could be leeched out of the brushes when the ventilating air duct connected to the generator happens to direct water onto the commutator and brushes. That is the reason why the easily soluble halides are less desirable as treating agents.

Difficulties also arise in the case of halides which are thermally unstable to such a degree that dissociation of the compound takes place, not only at the brush-commutator interface, but throughout the brush itself. The ideal halide should be thermally stable to temperatures up to those attained in the face of the brush. Another major objection to a great many halides is the fact that they adsorb water and dissolve in it. Or, one or more of the thermal-decomposition products may deliquesce in air or react so as to leave an undesirable residue in the brush or on the commutator.

The lead formed by the thermal decomposition of lead iodide may remain in the brush either as lead or as lead oxide. Some of it may be mechanically transferred and enter as an impurity into the copper-oxide film on the commutator. In any case, the physical and chemical properties of the solid residues are such that they are not detrimental to commutation. A number of the other metallic halides that were tested gave nonuniform films and high contact drops even though they did prevent actual brush dusting.

The war needs necessitated the early adoption of a treated brush. Lead iodide was chosen in preference to others as the most promising halide treatment for the first large-scale application. Most of the *P*-1 generators now in service have been equipped with Stackpole brushes containing this treatment. Nevertheless, tests with other halides have continued both here and elsewhere, and it is believed that at the present time all heavy-duty generators placed on high-altitude bombers are fitted with brushes containing one of the metal halides as an antidusting agent.

A number of practical problems had to be solved in the initial application of the lead-iodide treatment. The temperatures at which electrographitic brushes are fired are so high that the iodide must be placed in the plate after manufacture. This may be done either by immersing the brushes in the fused salt or by carrying out metathetic reactions in the plate by successive immersion in the proper chemical solutions. The latter operation must be done with great care, as trace amounts of excess reagents or products of reaction often affect brush performance disastrously, and the leeching out of small concentrations of such compounds is very laborious.

Many of the halides can be incorporated into metal-graphite brush grades at the time of molding. Some halides are so unstable that they react with the copper in the brushes at all practical molding temperatures. While lead iodide can be molded successfully into metal-graphite grades, care must be taken in the curing of the brushes; otherwise undesirable reactions take place between the copper and the iodide.

Brush treatments which are capable of maintaining an oxide film on a heavily loaded commutator operating under the adverse conditions encountered in the upper air certainly warrant a trial in difficult brush applications at more normal levels. Man power and material limitations have severely handicapped the execution of such tests. However, in such severe service as is imposed on the brushes of high-speed electric locomotives halide treatments definitely have improved commutator conditions and increased brush life. Recently a group of test brushes was removed from a locomotive after 85,000 miles of high-speed service. The brushes are in excellent condition, and the wear has averaged only ten mils per thousand miles of service.

Exploratory applications have been made in other fields where commutating conditions are unusually difficult. Each application presents a new problem. In all cases, the brush grade and the type and the amount of treatment must be properly matched to the machine and to the operating conditions. Though progress necessarily has been slow, experience has now been accumulated to prove that this new purely chemical approach to the old problem of forming and maintaining a satisfactory copper-oxide film on commutators and slip rings will prove as effective in many ground applications as it was in its initial one, namely, the solution of the high-altitude brush problem.

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Chemical Contamination as Causes of Electrical-Insulation Failure

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Synopsis: Electrical-insulation failures were investigated and found to be due to chemical contamination with ionizable materials. Examples of such contamination are certain types of hand creams, soldering fluxes, and germicides in lubricating oils. Contamination mechanisms often involve operations which are otherwise insignificant in manufacturing processes. The effect of these materials on the electrical characteristics of the insulation is reported. The need for close correlation of industrial-hygiene manufacturing processes, insulation design, and quality control is emphasized.

ELECTRICAL-INSULATION troubles sometimes occur which baffle the observers. Frequently the failure is attributed to some entirely innocent cause. Several such failures when carefully studied were found to be caused by the presence of ionizable substances which when dry were not harmful but when exposed to humidity were a constant hazard in the presence of a voltage differential. The insidious behavior of such materials in insulation may allow apparatus to pass a high-potential test and subsequently cause failure during a less severe test or in service. Furthermore, the presence of ionizable materials near a damaged spot in insulation increases the hazard manyfold. As insulation ages and the protective varnish coating deteriorates, these contaminants become a more active hazard to insulation. Harmless-appearing substances such as hand creams and soldering fluxes may be sources of chemical contaminants which cause inestimable damage.

As a consequence, investigations of such failures must be thorough and include each component material down to and including the glass, mica, cotton, and other material which make up the insulation. Careful attention should be paid to recent changes in methods or technique and even to safety and hygiene campaigns. The examples which follow illustrate only a few mechanisms of chemical contaminations.

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Soldering Fluxes

Several years ago trouble was experienced with a number of cases of short-circuited commutators as a result of unauthorized use of zinc-chloride soldering flux. One commutator in particular for an experimental motor was an outstanding example. After several short circuits occurred, the bar-to-bar insulation resistance was checked. Seventy bars out of 300 had far below normal insulation resistance, which were about 0.1 megohm instead of above ten megohms. Upon application of a 60-cycle dielectric test it was found that bars with low insulation resistance stood a 200-volt test but generally broke down at 400 volts. Bars with normal insulation resistance withstood a 600-volt test and failed at not less than 800 volts.

Mica segments were removed from the spots having low insulation resistance for chemical tests in comparison with uncontaminated mica segments. A 15-gram sample of each mica segment was boiled with 15 milliliter of distilled water and the conductivity of the solution determined as shown in Table I.

This test clearly indicated the presence of ionizable contaminants in the low-resistance mica segments which increased the conductivity of the extracted solution by a factor of more than ten to one as compared to a similar extract of uncontaminated insulation. Chemical analysis of the solutions clearly indicated the presence of zinc and chlorine in the low-resistance solutions, whereas the control specimens had less than one part per million of either.

Erikson[1] points out the effects of a combination of soldering flux and moisture on fine-wire magnet coils. Failures were due to corrosion of copper by fluxes which caused open circuits. Failures to ground and short circuits due to electrolytes from the corroded copper and from the soldering fluxes themselves forming conducting paths are also possible in this type of application.

Fluxes are available in many forms. The acid type, zinc and ammonium chloride, are available in water solution or in the form of a paste using a petrolatum or other grease vehicle. Milder fluxes include rosin and alcohol solutions and rosin-petrolatum pastes. An example of a zinc-chloride water solution on mica V rings has been discussed previously. Zinc chloride, the electrolyte on these V rings, was deposited from water solution throughout the insulation. Under humid conditions these electrolytes formed a conducting path which leads to the burning of the mica as seen in Figure 1. Zinc- and ammonium-chloride fluxes in water contribute to corrosion of copper.

The effect of zinc chloride on insulation under moist conditions is summarized in Table II. These results were determined on sample coils similar to those shown in Figure 2 and on mica by a jig similar to that shown in Figure 3. Sample coils had been immersed in zinc-chloride solution and others in distilled water for two days and then allowed to stand in air for

Figure 1. Typical failures of commutator mica V rings due to acid flux on segments

Table I

Segment Identification	Resistance (Ohms)
2	600
13	1,000
20	1,200
21	950
23	950
24	1,210
35	590
Uncontaminated control segment	13,600
Uncontaminated control segment	16,000
Fresh distilled water	35,000

Table II. Insulation Resistance in Megohms

Wire Insulation Used	Soaked in Flux for 48 Hours, Stood in Air 7 Days	Soaked in Distilled Water for 48 Hours, Stood in Air 7 Days
Asbestos	0.15–43	4,000
Glass	15 –29	1,800
Glass (silver)	3.8 –18	3,000
Double cotton	16 –39	72
Mica*	0.25– 0.30	30–75

Fluxed samples were soaked in the following solution for 48 hours:

Zinc chloride	1 pound
Ammonium chloride	2 ounces
Water	3.3 gallons

These together with the distilled-water-soaked samples were allowed to stand one week in the air before testing.

* Aged one week at 100-per-cent relative humidity

seven days. Insulation resistances of the coils then were taken and are reported in Table II.

Insulation resistance of cotton-covered wire was poor after this treatment in distilled water but was even lower after the acid flux treatment. The asbestos-insulated wire after treatment in flux had an insulation resistance of 0.5 per cent of that treated in distilled water. Mica behaved in a manner similar to the wire insulation.

Zinc chloride or ammonium chloride may be mixed into a petrolatum vehicle as a paste. In this form corrosion and electrical failures due to use of acid fluxes may be apparently reduced. The dangerous electrolytes still are introduced into the insulation; their effects are merely postponed. Under humid conditions, particularly after the petrolatum vehicle has disappeared, the zinc and ammonium chlorides become conductors. They lower insulation resistance and decrease breakdown strengths of insulation. This leads to failures in service rather than failures in tests during manufacturing the latter which might occur if water solutions of these fluxes were used.

Rosin and alcohol, another type of soldering flux, are relatively safe for use near insulation. No electrolytes are deposited, and the corrosion problem is greatly reduced. This flux has been in use many years without causing failure epidemics.

Each worker should be informed thoroughly as to the proper flux for his application. Acid-type fluxes may be used on parts which are not insulated if the flux deposits are washed carefully from the metal after completion of the operations. No form of soldering flux which contains zinc chloride, ammonium chloride, or other electrolytes should be tolerated for use near insulation. Rosin in alcohol solutions, or other organic nonelectrolytic types of flux, should be used in all doubtful cases. The security in using an electrolyte in grease mixture as a flux is false. It should be remembered that these electrolytes will ionize and become conducting under humid conditions, and, in addition, many of these substances are hygroscopic and thus will become conducting in only moderate humidity conditions.

Figure 2. Coil for testing soldering fluxes on insulation

Hand Creams

The use of hand creams in shop practice was suspected as a cause of insulation failures. Protective-hand-cream use was being encouraged in varnish-treating rooms, in coil-insulating, and wire-insulating departments as insurance against dermatitis. Such creams are effective in prevention of irritation due to varnish solvents and adhesives. However, investigation proved many creams contained conducting materials which are corrosive to copper or harmful to insulation.

Schwartz[2,3] points out that ointments fall into a number of classes:

1. Simple vanishing-cream types which fill the pores with soap and facilitate removal of soil when washing after work.

2. A type which leaves a thin film of resin or wax on the skin and thus prevents the irritant from direct contact with the skin.

3. A third type which fills pores and covers the skin with a harmless fat that repels water-soluble irritants and prevents entrance of petroleum oils, greases, and coal-tar derivatives.

4. A fourth type which contains nonirritant chemicals intended to detoxify the irritants.

5. Another form which causes inert powders to adhere to the skin, forming a physical barrier against skin irritants.

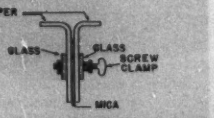

Figure 3. Device for testing soldering fluxes on mica

A series of determinations was made to discover the conducting properties of the various hand creams in use in the shops and the effect of ointments and humidity on ointment-contaminated insulation. Six-mil filter paper was wrapped around five-eighths-inch-diameter glass tubes. Various creams were rubbed into the paper, and the insulation resistance was determined between two electrodes $1\frac{1}{2}$ inches apart. These tests were conducted at 20-, 50-, and 97-per-cent relative humidity. Test bars also were prepared of asbestos-insulated wire onto which various creams had been applied. These wires were tested for insulation resistance between strands and for dielectric breakdown.

It was found that those creams which had soap bases and were therefore alkaline in reaction became conducting at higher humidities and lowered insulation resistances. This is reflected by the lower insulation resistances of certain hand creams upon the porous paper tubes (Table III). Hand creams lowered the insulation resistance and dielectric breakdowns when test bars of asbestos-insulated wire were subjected to hand creams and humidity (Table IV). These humidity conditions approximate summer weather conditions. The hand creams which proved most troublesome

Table III. Effect of Hand Creams on Insulation Resistance in a Humid Atmosphere

	At 20–30-Per-Cent Relative Humidity (Megohms)	At 50-Per-Cent Relative Humidity (Megohms)	At 97-Per-Cent Relative Humidity (Megohms)
A	950	17	0.095
B	Over 1,000,000	22,000	1.3
C	200,000	200	0.06
D	Above 200,000	8,000	2.5
E	Above 200,000	6,500	4.6
F	Above 200,000	20,000	7.7
G	Very high	150,000	12

Conductance in water solution was measured in a cell with platinum electrodes by an a-c conductivity bridge at 20 degrees centigrade after suspending the creams in 20 parts of water

	Resistance in Ohms
Distilled water	156,000
A	975
B	2,600
C	750
D	4,370
E	19,300
F	4,500

A = alkaline soap base
B = neutral grease
C = alkaline soap base
D = neutral grease
E = lanolin and olive oil
F = alkaline soap base
G = blank paper

A contains Bentonite clay.

C is a clear solution in water when hot, setting to a gel on cooling, like soap. Both these contain water and are mildly alkaline.

C has a tendency to turn copper green.

B contains grease and no water, with a mineral filler. It is neutral in reaction.

D and *E* are neutral greases.

F is alkaline in reaction. These do not contain water.

Table IV. Insulation Resistance and Dielectric Breakdown on Asbestos Wire Test Bars

Cream Used	Insulation Resistance (Megohms) At Room Condition	Insulation Resistance (Megohms) After Conditioning at 70-Per-Cent Relative Humidity	Dielectric Breakdown In Volts (Failed at) At Room Condition	Dielectric Breakdown In Volts (Failed at) After Conditioning at 70-Per-Cent Relative Humidity
A	500– 1,400	8 and 14	1,500	2,000
B	11,000–13,000	120 and 130	2,000	2,500
C	1,800– 2,000	0.08 and 0.08	2,000	800–800
D	13,000–13,000	5 and 4.6	2,000	2,500
No cream	1,400– 2,300	10 and 8.5	2,500–2,000	2,000–2,500

A = alkaline soap base *B* = neutral grease *C* = alkaline soap base *D* = neutral grease

Test conditions:

Strands rubbed with protective hand creams, formed into straight-side test bars, and hot pressed.

All tests made between two conductors at room conditions (20–30-per-cent relative humidity), and after conditioning 48 hours at 70-per-cent relative humidity, and 25 degrees centigrade.

Test bars were allowed to stand one week before testing.

were of the alkaline soap-base vanishing-cream type.

One of these soap-base hand creams was applied to copper panels which were dipped into varnish. The cream tended to dissolve in the varnish, thus contaminating it, and to melt and run during the baking operation. As a consequence a very poor film resulted which suffered a 75-per-cent decrease in dry dielectric strength over a control panel prepared clean and free of hand cream.

On the basis of these data, the hand creams used in manufacturing were limited to the types which leave a thin film of resin or wax on the hands but which are neutral in reaction. The use of these hand creams is not detrimental to insulation if moderation is practiced. However, each hand cream used should be investigated thoroughly by the engineers and industrial-hygiene department before its use is authorized.

Germicide Additions to Lubrication Oils

An excellent example of the type of failures produced by contamination of insulation with ionizing materials is shown in Figure 4. This was found to be due to the addition of a very small percentage (0.4 per cent) of germicide to the compound used for lubricating the blocks for pressing armature coils to size. Tests showed that the addition of one per cent of the lubricating compound to the germicide raised the conductivity of distilled water by a factor of ten, and the addition of one per cent of the germicide raised the conductivity of distilled water by a factor of 200. Chemical analysis of the coil-insulation and winding material adjacent to this failure disclosed no inorganic salts (sodium zinc, chloride, or sulphates). The germicide used was of the phenolic type. A phenol coefficient of at least 18 (Federal Druggists Association method) was specified. This is not, however, a measure of the compound's conducting properties. However, phenolic-type compounds are acidic and hence conductors; organic germicides of this type are chemical relatives of carbolic acid. Insulating materials pressed in molds lubricated with the compound having germicide were found to have high conductivity when humidified. The evidence appeared to be conclusive that this was the cause of the creepage failure shown in Figure 2.

Motors Operating in Chemical Plants

A more obvious type of failure due to chemical contamination occurred in service. A large motor with class-*A* insulation was installed in a magnesium plant. After eight months service this motor was found to have three grounded field coils. Scrapings from the windings were analyzed by microchemical methods. The material was found to be chiefly magnesium chloride and other hygroscopic salts. This contaminant did not deteriorate the varnish film but formed a conducting path through cracks in the film and around the leads into the coil. Magnesium chloride also will decompose cotton insulation.

Adhesives Used in Asbestos Wire Insulation

The adhesive used to bond asbestos insulation to wire was found to be the cause of certain failures. A casein-type glue in water solution had been used. A change in formulation by the manufacturer had introduced inorganic salts These, sodium carbonate and sodium phosphate, are electrolytes and in humid conditions corroded the copper. The insulation turned green, and failures resulted during standard proof tests. Inadequate drying of the glue contributed to the corrosion and allowed ionization to take place which led to early test failure of many of these coils. This situation was corrected by use of an organic-type synthetic adhesive which contained no inorganic salts.

Figure 4. Creepage failure of armature coil due to conducting germicide in press lubricant

Carbon-Dioxide-Type Fire Extinguishers

Proper construction of varnish tank systems should include some fire-control device. Frequently fire extinguishers are so arranged that they will release automatically in case of fire. In some cases, the extinguishers accidentally will set off and spray the surface of the varnish with the extinguisher's contents. Foamite-type extinguishers often are used which consist of a small container of an inorganic acid and a larger one of sodium carbonate. When mixed, carbon-dioxide gas will be formed which propels the mixture from the extinguisher and sprays the varnish with a mixture of electrolytes: unreacted acid, unreacted sodium carbonate, carbon dioxide, water, and the sodium salt of the inorganic acid. This contaminates the varnish with electrolytes and water, thus lowering its insulation qualities. Filtration methods[4] will not remove this type of contaminant. The use of this contaminated varnish would introduce electrolytes into the insulation which would prove as detrimental to the machine as the other types of ionizable chemical contaminants already discussed.

Conclusions

Causes of insulation failures which may seem obscure or mysterious may be due to chemical contaminations. Chemicals introduced into the insulation in manufacture, repair, or service may be of the electrolytic type and reduce the insulation resistance and dielectric breakdown of the insulation. They may be of a type which

A New Outdoor Air Switch and the Principles Involved in Its Design

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THE OUTDOOR air switch is a universally used device which through the years has evolved into a few well-known types. Increasing preference has been shown for the rotating-insulator vertical-break switch, which has become almost a standard for outdoor service. A new switch of this type is described, and a discussion of the problems associated with its design is presented.

It may seem, at first glance, that the design of air switches should have been reduced to a few simple calculations and a few hours' work on the drawing board. As a matter of fact, their correct design requires a long period of development, including many calculations and laboratory tests. It is a comparatively simple task to design a switch that fulfills the essential requirements when new, but it is much more difficult to design an economically practical switch that will retain its characteristics after years of use outdoors where sun, wind, ice, and dust prevail and where corrosion is always at work. In the course of development of a new outdoor switch, a thorough study was made of the basic problems involved without regard to existing opinions on the subject. A complete review and analysis of past and present-day switch designs followed to determine the relative merits and defects of each. This study led to new approaches to some of the problems including the use of recently developed materials.

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Design Problems

Reduced to its essentials a switch consists of two terminals, a blade hinged on one terminal to open and close the circuit between the terminals, a suitable base for mounting, and insulation between the terminals and ground. Past experience with air switches indicates that the contacts between the blade and the terminals are likely to be the chief source of trouble. For this reason, the subject of contacts must be given first consideration in the design of any switch. That there is a wide divergence of opinion on the subject is shown by the fact that almost every known type of contact can be found on present-day switches.

The blade mechanism—that is, the means for converting rotation of the insulator into the desired blade motion—is the second consideration. The type of blade mechanism selected is the determining factor in the ability of the switch to operate with ease under both normal and adverse conditions. The choice of a mechanism for performing this operation is influenced by the type of contacts adopted, since certain types of contacts require a more elaborate mechanism than others, if the switch is to operate easily and reliably.

Fortunately, the insulation no longer presents a problem to the outdoor-switch designer. As a result of excellent work of standardization committees, electrical and mechanical properties of outdoor air switch and bus insulators, as well as minimum spacings for switch insulators, all have been standardized. The resulting advantages to user and manufacturer are obvious.

Contacts

There are only two major requirements of air-switch contacts:

1. They must carry their rated current without reaching injurious temperatures, not only when new, but also after many years of service.

2. They must carry without injury the maximum short-circuit current of the system to which they are applied, until this current is interrupted by a circuit breaker. This ability also must be maintained for the life of the switch.

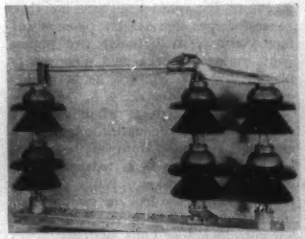

Figure 1. The new disconnecting switch, 69-kv 600-ampere rating

Low contact resistance is necessary to meet both of these requirements. As early as 1892[1] the importance of the total pressure in regard to its effect on contact resistance was realized. In 1913 F. W. Harris[2] showed that the contact resistance varies inversely with the total pressure and is substantially independent of the

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is harmless when dry and at room temperatures, but which will become conducting under high humidity conditions, particularly when hot. The contaminant may cause metallic corrosion which produces electrolytes, and this tends to accelerate failure. Failures due to contaminations may occur in epidemics in factory testing or may not occur until the machine is in field service.

Close co-operation between the manufacturing, hygiene, and engineering departments is necessary to control this problem. Each worker should be educated in the importance of his operation on the final product and the ever-present danger that he may introduce dangerous chemicals into insulation from apparently harmless sources. All precautions should be taken, particularly in the use of new materials, to see that toxicity and irritation are eliminated, but not at the expense of insulation quality. Hygiene campaigns should be co-ordinated with insulation engineering to protect both the workers and the apparatus quality.

Both materials in everyday use and those which are new material should be investigated thoroughly as possible sources of contaminations. Use of chemicals even for insignificant-appearing jobs should be reviewed. Review of soldering fluxes, for instance, is essential.

Changes in manufacturing technique should be considered carefully. A small change may cause more damage than more obvious changes. Possible sources of chemical introductions into insulation should be investigated thoroughly, and the harmful effects of this type of contamination should be kept ever in mind.

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area. This was confirmed some years later by A. R. Enger,[3] who found experimentally that the temperature rise of switch contacts was not increased appreciably by slight misalignment of the blade in the switch jaw, since this decreased the contact area but increased the unit pressure. In 1928 a mathematical relation between the contact resistance and the total pressure was developed by W. Schaelchlin.[4] He showed that

$$R = cP^{-k}$$

where R is the contact resistance, c a constant depending on the material and shape of the contact, P the total pressure, and k a constant which may have any value from 0.5 (if the number of contact points remains constant as the pressure increases) to 1.0 (if the number of contact points increases linearly with the pressure).

The shape of contacts is important, inasmuch as it affects unit pressure and the amount of material immediately adjacent to the contact. There are three general shapes of contacts: plane or surface contact, as between two planes; point contact, as between a sphere and a plane; and line contact, as between a cylinder and a plane.

The surface contact when new and clean is entirely adequate for both rated and fault current. However, because of low unit pressure it is extremely susceptible to corrosion. While formerly widely used on outdoor air switches, the surface contact now is used chiefly for low-current indoor knife switches.

The point contact, used to some extent in air switches,[5] meets the requirements of high unit pressure and low contact resistance and is completely adequate for carrying rated current. However, under fault conditions the small amount of metal adjacent to the contact limits the rate at which heat is conducted away and thereby limits the short-circuit current that can be carried without damage.

The line contact has found increasing use in recent years and has proved very satisfactory. B. W. Jones[6] determined experimentally that, with copper contacts and pressures between 10 and 500 pounds, one inch of line contact has only one half to one third the resistance of a surface contact one inch square. This results in excellent characteristics under normal load currents. The amount of material adjacent to a line contact available for heat conduction is inherently greater than that adjacent to a point contact and is, therefore, able to carry the heat away from the contact more rapidly with the result that much higher fault currents can be carried without damage. This principle is used widely in the high-pressure single-line switch contact and the modern medium-pressure, multiple-line contact.[7]

The material for contacts must be selected on the basis of its resistivity, chemical activity, hardness, and annealing temperature. The initial contact resistance varies directly with the resistivity of the contact material.[3] However, this resistance tends to increase with age, due to the formation of surface films. The base metals, such as copper and its alloys, form a high-resistance oxide film when exposed to air, the rate of oxidation being comparatively low at room temperature, but becoming more rapid at elevated temperatures. The noble metals do not oxidize in air, but silver, which is a widely used contact material, does react with sulphur in the atmosphere to form silver

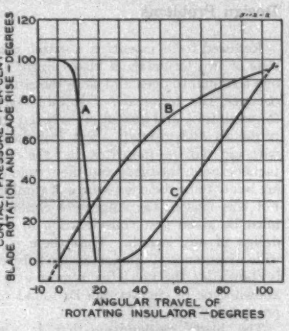

Figure 2. Curve showing relative motion of moving parts

A—Contact pressure in per cent
B—Blade rotation in degrees
C—Blade rise in degrees

sulphide. However, this film has comparatively low electric resistance, is thin, and is easily rubbed off. The high electric and thermal conductivity of silver make it an ideal material for indoor or enclosed locations where a medium-pressure contact is satisfactory.

Contacts exposed to the weather must meet additional requirements, since dirt, dust, and corrosion accumulate more rapidly and since there is likelihood of ice formation. Here the contact must have sufficient pressure to break through coatings of ice, dirt, and corrosive films. Even in enclosed locations, rubbing action, desirable on silver, is essential on copper and its alloys in order to remove corrosion from the surface. In high-pressure rubbing contacts soft metals, such as silver and copper, are subject to excessive wear and galling, and harder alloys must be used. These alloys must not anneal when heated to temperatures of several hundred degrees centigrade, which may be reached under short-circuit conditions.

Both flexible shunts and contacts are used on the hinge end of outdoor switches at the present time. Shunts are subject to oxidation and corrosion, particularly in sulphurous industrial atmospheres, and the combination of corrosion and flexing may break the fine wires until eventually the shunt breaks completely. The same conditions that cause rapid deterioration of shunts also cause rapid deterioration of exposed contacts. At the break jaw contacts necessarily must be left exposed. At the hinge connection, however, it is not necessary to use either a shunt or an exposed contact, since the contacts can be completely enclosed, protecting them from the elements and, to a great extent, from corrosive atmospheres.

Blade Mechanisms

There are two chief requirements of blade-operating mechanisms:

1. They must permit easy operation of the switch, even after a number of years in service with infrequent operation.

2. They must permit operation of the switch when it is covered with ice.

The effort necessary to operate switches is due entirely to friction, except in the opening operation on small switches where the weight of the blade is not counterbalanced. The only essential friction is that produced by the rubbing motion in contacting the switch. This motion should be separated from the blade-elevating motion and accomplished with maximum mechanical advantage. All other friction is incidental to switch operation and should be reduced to a minimum. For this reason, the number of pins and bearing points should be as small as possible. In normal service wear on a disconnecting switch can be neglected and, without maintenance, its life depends on freedom from corrosion of bearings and contact surfaces. Even though bearings must be made of materials that are corrosion resistant, they still should be designed with ample clearances so that corrosion will not cause seizing.

The earliest rotating-insulator vertical-break switches were merely hook-stick-operated switches with the hook-stick eye omitted and with a third rotating insulator added. A crank at the top of the rotating insulator raised and lowered the blade. In 1924 Koppitz conceived the earliest of the modern dual-motion switches. These switches utilize a second motion, usually a continuation of the first (blade-closing) motion to apply contact pressure during or after entry of the blade into the break jaw. This contacting motion makes use of a much greater mechanical advantage than is available for the blade-closing motion. The dual-motion switch made possible the high-pressure switch contact as known today.

Contact pressure can be applied in a number of ways. In some switches the blade is pushed forward into the break contact. In others contact tips are ex-

panded by two blade members to engage the break jaw. Still others use a flat blade tip which is rotated in a resilient break jaw to establish contact pressure. Though each of these has its advantages, it must be kept in mind that each additional bearing is one more point to corrode and stick; each additional link or lever is one more part which may break or become frozen in ice. The mechanism should, therefore, be as simple and contain just as few moving parts as possible.

Description of Switch

The switches designed as a result of these studies are unique in their simplicity with only three moving parts and one exposed contact. The 69-kv 600-ampere pole unit shown in Figure 1 is typical of the line of switches, which are of the rotating-blade type. The rotating-blade motion was chosen because it permits application and release of contact pressure at the break jaw with a single blade member and with maximum mechanical advantage. It obviates the necessity for a number of parallel links at the hinge end, and it eliminates the possibility of cantilever stress on the jaw insulator due to switch operation. It further permits large deflections of the break-jaw insulator stack due to stresses from connecting lines or busses without affecting operation of the switch.

As the switch is opened, the blade is rotated until the contact pressure is fully released, then with the contact completely free the blade is elevated to the open position. In closing the reverse sequence is followed. The contacting motion is accomplished with high mechanical advantage to overcome the high frictional forces. After contact pressure is released, these forces are no longer present, and the blade is raised easily. This complete release of contact pressure before vertical movement of the blade is essential for easy operation. The relations between insulator rotation, blade rotation, and blade rise are shown in Figure 2. This ideal sequence of blade motions has been accomplished by the use of independent means for performing the two functions.

The mechanism for obtaining this sequence of motions is shown in Figure 3. An operating arm, bolted to the top of the rotating insulator stack and pivoted in the hinge support, engages two separate parts to give the independent motions. The blade-elevating motion is obtained through the action of the roller at the end of the operating arm in a slot on the inside surface of the mechanism housing. This slot is designed so that the portion corresponding to the first 27.5 degrees of insulator rotation lies on the circle traversed by the roller in revolving about the center line of the insulator stack. The housing and axis of the blade therefore remain stationary, while the roller rolls in this portion of the slot, rotating the blade only on its own axis. The next portion of the slot is inclined so that the blade is accelerated uniformly to its final velocity, which is maintained to the full open position by uniform rotation of the insulator.

The contacting motion is accomplished through a forked crank rigidly fastened to the hinge end of the tubular blade, engaging the operating arm in such a way that rotation of the arm results in rotation of the blade. The physical relation of the arm and the fork is such that one degree of movement of the rotating insulator twists the blade approximately two degrees when the blade is within the jaws. The rapid initial twisting of the blade permits complete disengagement of the contacts before the elevating movement of the blade begins. Figure 4 clearly shows the sequence of these motions.

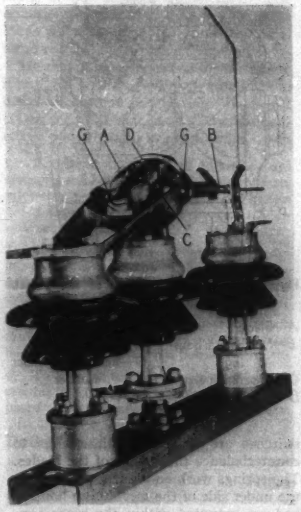

Figure 3. Early model of the new switch with special cutaway housing, which shows the mechanism for operating the blade (hinge contact not shown)

The tubular blade *B* is mounted in the mechanism housing *A*, free to rotate on its own axis. The fork *D* is part of the blade and rotates with it. The housing *A* rotates about the horizontal axis formed by the hinge bearings *GG*. The operating arm *C* extends through the fork *D*, and a roller at its outer end rolls in a groove in the inner surface of the housing *A*. To operate the switch the center insulator is rotated by turning the lever near the base. This rotates the operating arm *C*, which is bolted to the top of the rotating insulator. During the first 27.5 degrees of rotation of the operating arm, the arm engages the fork and rotates the blade to release the contact pressure on the jaw at the far end of the switch. Then the roller strikes the inclined portion of the groove, and, since the roller is constrained to revolve in a horizontal plane, the housing is rotated until the blade reaches a vertical position

Figure 5 is a top view of the center portion of the switch indicating the current path and showing the general arrangement of the hinge contacts. One end of the internal contact member bears against the heavy hinge stud to form a self-aligning annular-line contact. The other end bears against a machined surface on the fork to form a straight-line contact, which is also self-aligning. Contact pressure is supplied by a compression spring with adequate deflection so that the loss of contact pressure would be negligible even under the most severe conditions of contact wear. The hinge stud is threaded in the tie casting and locked against turning by a special locking washer and lock nut, which maintain intimate high-pressure contact at this point.

The mechanism housing completely encloses the hinge contacts and protects the moving parts from ice formation, so that the switch can be operated readily under heavy ice and sleet conditions. Furthermore, because the parts are protected from sun, rain, dust, and harmful atmospheric gasses, corrosion is very greatly reduced inside the enclosure, and lubrication is unnecessary.

Troubles due to annealing of work-hardened nonferrous materials, such as hard copper and phosphor bronze, have been eliminated by the use of precipitation-hardened (heat-treatable) alloys at the break contact. The jaw is beryllium cobalt copper, a comparatively new but already well-known and proved material. Under short-circuit conditions beryllium cobalt copper will not be affected at temperatures which would completely anneal work-hardened copper or phosphor bronze. This guarantees that the hardness of 90 Rockwell *B* and tensile strength of 90,000 pounds per square inch will be maintained for the life of the switch. As the physical characteristics of the material will be unchanged throughout the life of the switch, the jaw itself is used as the spring member as well as the current-carrying part.

The formed contact over the flattened end of the blade is chromium copper. This alloy, developed within the past decade, is similar to beryllium cobalt copper in that it is also precipitation-hardened. Though its strength and hardness are not so great, it has an electric conductivity 80 per cent that of copper, as compared with 45 per cent for beryllium cobalt copper. Hence, it is an ideal material for contacts in which extremes of hardness and deflection are not required.

Figure 4. Three views of the switch of Figure 3 showing the blade in various positions

The beryllium–cobalt–copper jaw and chromium–copper contact tip permit high-pressure rubbing line contact capable of breaking up and wiping away coatings of dirt or oxide. The break jaw has adequate deflection to shatter ice formations. The dissimilarity in the contact materials assures a minimum of wear and eliminates the possibility of galling. These factors, together with the non-annealing characteristics of the alloys, assure that the break contact characteristics will remain unchanged after years of severe service even under extreme climatic or atmospheric conditions.

Ease of operation has been considered essential in the design of these switches. The enclosed blade mechanism just described provides high mechanical advantage during the contacting operation where friction is greatest. Friction has been reduced elsewhere by the use of a minimum number of moving parts and bearings. The rotating insulator columns of switches above 15 kv are equipped with either dry-type ball bearings or with roller bearings having pressure fittings for easy lubrication. In the higher-voltage and higher-current ratings, the switches are provided with springs to counterbalance the weight of the blades. The springs work on an arm attached to the under side of the mechanism housing and are mounted within the hinge support for complete protection from the weather.

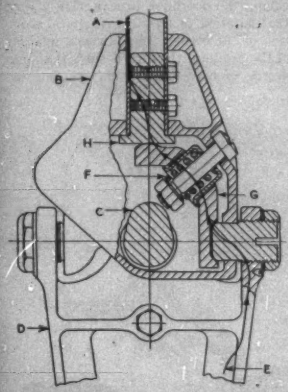

Figure 5. Partial top view of the switch showing construction of hinge contacts

A—Blade
B—Mechanism housing
C—Operating arm
D—Hinge support
E—Current path
F—Spring
G—Internal contact member
H—Fork

Tests

In the development of this switch numerous models were built and subjected to tests to check their performance under normal and extreme operating conditions. Temperature-rise tests were made on all ratings to insure that the switches would carry their rated current with a temperature rise of less than 30 degrees centigrade. Pole units were operated as many as 10,000 times to check wear on contacts, bearings, and operating mechanism parts. Short-circuit tests were made on all ratings to insure that the switch would carry its rated short-circuit current without mechanical injury and without damage to the contacts. To check their ability to operate properly under ice and sleet conditions, various ratings of switches were operated when covered with over a half inch of ice. Tests have been made to verify the effectiveness of the smooth contours in reducing corona and radio interference. Though flashover and withstand tests are considered insulator characteristics, 60-cycle wet and dry tests and impulse tests have been made to check over-all switch characteristics.

Summary

The new outdoor air switch strikes a new note in simplicity, as it has only three moving parts. All parts are simple and rugged with stresses kept to safe values for the materials employed. Hinge contacts and live parts with relative motion are protected from rain, dust, corrosion, and ice by a housing having smooth contours to minimize corona losses and radio interference. Critical adjustments and alignments have been eliminated. The sole exposed contact, at the break end, utilizes new materials which can withstand severe overcurrents and years of weathering without damage. Because of these features the new switch offers improved ease of operation and maximum reliability under all conditions.

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Design of Induction-Heating Coils for Cylindrical Nonmagnetic Loads

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EQUATIONS are presented for the calculation of the required number of coil turns to match a given power source for solenoidal coils with coaxial cylindrical loads of nonmagnetic materials in electromagnetic induction circuits. The equations apply to both solid and hollow loads. A correction factor is established for coil shortness providing the coil length is equal to or greater than the coil diameter. Also given are equations for power distribution and impedance values. The accuracy of the calculations is substantiated by experimental results.

At the present time induction heating of nonmagnetic materials is used in annealing, forging, brazing, melting, heating for shrink-fitting, and other purposes.

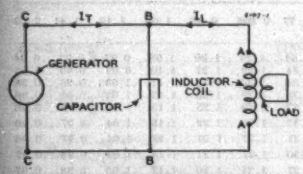

Figure 1. Conventional induction heating circuit using motor generator set

In any application a proper match must be obtained between the heating circuit and power source. In the case of multiturn coils connected directly to the output of a constant-frequency generating device, if the coil has too few turns, the output voltage is low at the rated output current of the generator. Consequently rated power output from the generator cannot be realized without employing some other matching device (transformer or series reactor). If the coil has too many turns, at rated generator output voltage, the current is low. To obtain the desired match to a given power source with a direct connected inductor, a specific number of coil turns must be used for any given physical dimensions. In the past determining the proper number of turns has been a cut-and-try process with many users of induction-heating equipment.

Baker[1] has presented equations for calculating the electrical characteristics of solenoidal coils with coaxial cylindrical loads of nonmagnetic conductors. The equations apply with accuracy to solid loads where the axial length of the coil is large relative to its inside diameter.

He also gives an equation for the power input to hollow cylinders where "the depth of current penetration" is several times the wall thickness. The purpose of the present paper is as follows:

1. To extend the range of equations applying to solid cylinders, so that accurate results may be obtained when the coil has an inside diameter of the same order of magnitude as its axial length.

2. To extend the range of equations applying to hollow cylinders so that accurate results may be obtained regardless of the cylinder wall thickness.

3. To present the equations in a form such that the required number of coil turns may be found to match a given power source.

4. To present tabulated values of experimental and calculated results over the proposed application range of these equations.

Definition of Symbols

Symbols used in appendixes are defined therein.

A = coil resistance divided by N^2, from equation 6
a_o = outside diameter of load, inches
a_m = average diameter of load, inches, = $a_o - b_2$
B = load resistance divided by N^2 from equations 9, 11, and 13
b_1 = inside diameter of inductor coil, inches
C = internal reactance of coil divided by N^2, from equation 7
D = internal reactance of load divided by N^2, from equations 10, 12, and 14
d_1 = reference depth for inductor, measure of current penetration, inches, from equation 15
d_2 = reference depth for load, measure of current penetration, inches, from equation 16
E = air-gap reactance divided by N^2, from equation 8
E_c = voltage across capacitor terminals BB, volts, from equation 23
E_L = voltage across inductor coil terminals AA, volts
E_T = voltage across generator terminals CC, volts
E_R = voltage rating of capacitor, volts
f = frequency cycles per second
h = radial thickness of inductor coil, inches
I_L = current through inductor coil, amperes, from equation 22
I_T = generator output current, amperes
K_1 = coil shortness correction factor, from equation 17
K_2 = resistance coefficient for thick wall and solid rods from Figure 5
K_3 = resistance coefficient for thin-wall rods from Table I
K_4 = reactance coefficient for thin-wall rods from Table II
K_5 = Nagaoka's constant[2] from Figure 4
L = axial length of inductor coil, inches
N = total turns in inductor
n = efficiency of power conversion through inductor to load, from equation 20
P_A = power dissipated in transmission line resistance R_A in watts, from equation 24
P_L = power input to inductor coil and load in watts
P_s = power dissipated in load in watts, from equation 19
P_T = total power input at capacitor terminals in watts, from equation 25
ρ_1 = resistivity of conductor material in inductor, ohms inches
ρ_2 = resistivity of load material, ohms, inches
s = space factor of inductor coil
t_1 = wall thickness of conductor in coil in inches
t_2 = wall thickness of load in inches
R_A = resistance of transmission line from capacitor terminals BB to coil terminals AA in ohms
R_p = resistance of inductor coil itself in ohms, from equation 1
R_s = resistance of load as reflected in inductor coil in ohms, from equation 2
W = axial width of conductor in inductor coil in inches
X_A = reactance of transmission line from capacitor terminals BB to coil terminals AA in ohms
X_g = reactance due to flux in air gap between coil and load in ohms, from equation 5
X_p = reactance due to flux between inside and outside radius of inductor coil in ohms, from equation 3
X_s = reactance due to flux within the load as reflected in inductor coil in ohms, from equation 4

Circuit Description

The conventional induction-heating circuit used with rotating generators is shown in Figure 1. The purpose of the capacitor is to adjust the power factor of the generator load as viewed from terminals CC to approximately unity. The power factor as viewed from terminals AA may be considerably in the lag. Adjusting the capacitor to a value such that load power factor as viewed from the generator terminals is unity, results in a higher current I_L flowing through the coil circuit than the generator

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output current I_T, allowing a given load power dissipation at minimum generator output current for a given generator terminal voltage.

The circuit from capacitor terminals through load is resolved as shown in Figure 2 when the intercircuit capacitance is negligible, as it generally is for induction-heating circuits of 15,000 cycles or below. The power accomplishing the load heating is dissipated in R_s. The power dissipated in R_4, the transmission-line resistance, and R_p, the inductor-coil resistance, should be kept as low as possible for most efficient heating. The power dissipated in the capacitor is generally negligible.

The physical detail of an induction-heating circuit consisting of a solenoidal coil and coaxial cylindrical load is shown in Figure 3. The inductor is shown as a single-layer solenoid wound with a tubular conductor of rectangular shape. A multilayer coil could be used but would result in less efficient power transfer to the load. The conductor is made tubular to permit the flow of a coolant to carry away the heat dissipated in the coil. A round conductor could be used but generally results in a somewhat less efficient heating circuit.

In the inductor-coil circuit, the values R_p, X_p, X_o, X_s, and R_s determine the power dissipated for a given value of E_L. For given coil and load dimensions these values may be adjusted to obtain the desired power by changing the number of turns in the inductor.

Circuit Equations and Their Limitations

Equations

For derivations of the equations which follow see references 1 or 5 for the impedance values of solid cylinders, Appendix I for the impedance of hollow loads, and Appendix II for coil shortness correction factor.

Impedance values in coil circuit in ohms are

$$R_p = N^2 A \tag{1}$$

$$R_s = N^2 B \tag{2}$$

$$X_p = N^2 C \tag{3}$$

$$X_s = N^2 D \tag{4}$$

$$X_o = N^2 E \tag{5}$$

where

$$A = \frac{3.14 \rho_1 b_1}{sL}\left[\frac{1}{d_1}+\frac{1}{b_1}\right] \tag{6}$$

$$C = \frac{3.14 \rho_1 b_1}{sLd_1} \tag{7}$$

$$E = \frac{15.7 f (b_1^2 - a_o^2) K_1 10^{-8}}{L} \tag{8}$$

Equations 9 and 10 are used to determine B and D for solid rods. For hollow rods the equations used to determine B and D

Table I. Resistance Coefficient, K_1

For Hollow Rods Where Ratio of Wall Thickness to Reference Dimension $\frac{t_2}{d_2} < 2.0$ and ≥ 0.5

t_2/a_o \ t_2/d_2	0.500	0.522	0.545	0.569	0.595	0.621	0.648	0.677	0.707	0.74	0.77	0.805	0.88	1.00	1.19	1.41	2.00
0	2	1.93	1.86	1.78	1.70	1.64	1.58	1.51	1.45	1.39	1.34	1.29	1.20	1.08	0.97	0.92	0.94
0.025	1.96	1.89	1.83	1.76	1.70	1.64	1.58	1.51	1.45	1.39	1.34	1.29	1.21	1.10	0.99	0.93	0.95
0.0500	1.77	1.75	1.72	1.68	1.64	1.58	1.54	1.49	1.44	1.39	1.34	1.30	1.23	1.11	1.04	0.95	0.96
0.0648	1.60	1.60	1.59	1.58	1.56	1.53	1.50	1.46	1.42	1.37	1.33	1.29	1.23	1.12	1.04	0.95	0.96
0.077	1.45	1.47	1.48	1.48	1.48	1.47	1.45	1.43	1.39	1.36	1.32	1.29	1.23	1.13	1.04	0.96	0.96
0.084	1.35	1.38	1.40	1.42	1.44	1.43	1.42	1.40	1.37	1.34	1.32	1.28	1.22	1.13	1.04	0.97	0.96
0.092	1.24	1.29	1.32	1.35	1.37	1.38	1.38	1.36	1.35	1.33	1.31	1.27	1.21	1.13	1.04	0.97	0.96
0.100	1.14	1.19	1.23	1.27	1.30	1.32	1.34	1.34	1.34	1.32	1.30	1.27	1.21	1.13	1.04	0.98	0.97
0.109	1.03	1.08	1.13	1.17	1.21	1.24	1.26	1.27	1.28	1.27	1.27	1.25	1.20	1.13	1.05	0.98	0.97
0.119	0.91	0.97	1.03	1.08	1.14	1.17	1.20	1.22	1.24	1.24	1.24	1.23	1.19	1.13	1.05	0.99	0.97
0.130	0.80	0.86	0.92	0.98	1.03	1.08	1.12	1.16	1.18	1.19	1.20	1.20	1.18	1.13	1.06	0.99	0.97
0.141	0.68	0.75	0.82	0.88	0.94	0.99	1.04	1.08	1.12	1.14	1.16	1.17	1.17	1.13	1.06	1.00	0.98
0.154	0.57	0.62	0.68	0.75	0.83	0.89	0.94	1.00	1.04	1.08	1.11	1.13	1.16	1.13	1.07	1.01	0.98
0.168	0.46	0.53	0.58	0.63	0.72	0.79	0.86	0.92	0.97	1.02	1.06	1.09	1.14	1.13	1.08	1.01	0.99
0.183	0.38	0.43	0.48	0.54	0.60	0.66	0.73	0.81	0.88	0.94	1.00	1.04	1.09	1.13	1.09	1.02	0.99
0.200	0.28	0.33	0.38	0.43	0.49	0.56	0.62	0.70	0.77	0.83	0.91	0.97	1.06	1.12	1.10	1.03	1.00

Note: Values below heavy lines not checked experimentally.

Table II. Reactance Coefficient, K_1

For Hollow Rods Where Ratio of Wall Thickness to Reference Dimension $\frac{t_2}{d_2} < 2.0$ and ≥ 0.5

t_2/a_o \ t_2/d_2	0.500	0.545	0.595	0.648	0.707	0.77	0.84	0.92	1.00	1.09	1.19	1.30	1.41	1.54	1.68	2.00
0	0.33	0.36	0.39	0.43	0.47	0.51	0.55	0.60	0.65	0.70	0.75	0.80	0.86	0.91	0.95	0.99
0.0063	0.43	0.44	0.45	0.48	0.51	0.54	0.57	0.61	0.66	0.71	0.75	0.80	0.86	0.91	0.95	0.99
0.0088	0.47	0.46	0.47	0.49	0.52	0.55	0.58	0.62	0.67	0.71	0.76	0.81	0.86	0.91	0.95	0.99
0.0128	0.53	0.51	0.51	0.52	0.54	0.56	0.59	0.63	0.67	0.72	0.77	0.82	0.86	0.91	0.95	0.99
0.0177	0.61	0.57	0.56	0.56	0.57	0.59	0.61	0.64	0.69	0.73	0.77	0.82	0.87	0.91	0.95	1.00
0.0210	0.67	0.62	0.59	0.59	0.59	0.60	0.62	0.65	0.69	0.74	0.78	0.83	0.87	0.91	0.95	1.00
0.0250	0.73	0.68	0.63	0.62	0.61	0.62	0.63	0.66	0.70	0.74	0.78	0.83	0.87	0.91	0.95	1.00
0.0297	0.80	0.73	0.68	0.66	0.64	0.64	0.65	0.68	0.71	0.75	0.78	0.84	0.87	0.91	0.95	1.00
0.0384	0.80	0.79	0.74	0.70	0.67	0.67	0.67	0.70	0.72	0.76	0.79	0.84	0.88	0.92	0.95	1.00
0.0420	0.99	0.80	0.80	0.75	0.72	0.70	0.70	0.72	0.74	0.77	0.80	0.84	0.88	0.92	0.95	1.00
0.0500	1.09	0.98	0.88	0.82	0.76	0.74	0.73	0.74	0.75	0.78	0.81	0.85	0.89	0.92	0.95	1.00
0.0595	1.20	1.07	0.97	0.88	0.82	0.78	0.76	0.76	0.78	0.80	0.83	0.86	0.89	0.93	0.96	1.00
0.0707	1.31	1.18	1.07	0.96	0.89	0.84	0.81	0.80	0.80	0.82	0.84	0.88	0.90	0.93	0.96	1.00
0.084	1.40	1.30	1.19	1.07	0.97	0.90	0.86	0.84	0.84	0.86	0.89	0.91	0.93	0.96	1.00
0.100	1.46	1.38	1.28	1.18	1.07	0.99	0.93	0.89	0.87	0.88	0.88	0.90	0.92	0.94	0.96	0.99
0.119	1.49	1.46	1.37	1.27	1.17	1.08	1.01	0.96	0.92	0.91	0.90	0.93	0.93	0.95	0.97	0.99
0.141	1.44	1.46	1.43	1.36	1.28	1.20	1.11	1.04	0.99	0.96	0.94	0.94	0.95	0.96	0.97	0.99
0.168	1.36	1.42	1.44	1.42	1.38	1.30	1.22	1.14	1.07	1.02	0.98	0.97	0.97	0.97	0.98	0.99
0.200	1.23	1.34	1.40	1.44	1.44	1.41	1.34	1.26	1.17	1.10	1.04	1.01	0.99	0.99	0.98	0.99

Note: Values below heavy lines not checked experimentally.

depend on the relation t_2/d_2 and are as follows:

For hollow rods where $t_2/d_2 \geq 2.0$ and for solid rods

$$B = \frac{3.14\rho_2 a_o K_2 K_1^2}{L d_2} \tag{9}$$

$$D = \frac{3.14\rho_2 a_o K_1^2}{L d_2} \tag{10}$$

For hollow rods where $0.5 \leq t_2/d_2 < 2.0$

$$B = \frac{3.14\rho_2 a_m K_1^2 K_3}{L d_2} \tag{11}$$

$$D = \frac{3.14\rho_2 a_o K_1^2 K_4}{L d_2} \tag{12}$$

For hollow rods where $t_2/d_2 < 0.5$

$$B = \frac{15.7 f a_m{}^2 K_1^2 10^{-9}}{L} \times \frac{\frac{2d_2{}^3}{a_m t_2}}{1+\frac{4d_2{}^4}{a_m{}^2 t_2{}^2}} \tag{13}$$

$$D = \frac{15.7 f a_m{}^2 K_1^2 10^{-9}}{L}\left[\frac{a_o{}^2}{a_m{}^2} - \frac{1}{1+\frac{4d_2{}^4}{a_m{}^2 t_2{}^2}}\right] \tag{14}$$

The following equations are for determining values for use with the proceeding equations:

$$d_1 = 3{,}160\sqrt{\frac{\rho_1}{sf}} \tag{15}$$

$$d_2 = 3{,}160\sqrt{\frac{\rho_2}{f}} \tag{16}$$

$$K_1 = K_2\left(1-\frac{a_o{}^2}{b_1{}^2}\right)+\frac{a_o{}^2}{b_1{}^2} \tag{17}$$

The required number of coil turns to obtain given power P_L at given voltage E_L are

$$N = E_L\sqrt{\frac{A+B}{P_L[(A+B)^2+(C+D+E)^2]}} \tag{18}$$

Power dissipated in load, P_s in watts, is

$$P_s = P_L\left[\frac{B}{A+B}\right] \tag{19}$$

Efficiency of power conversion through inductor to load is

$$n = \frac{B}{A+B} \tag{20}$$

Capacitor rating for unity power factor at capacitor-terminal input is

$$\text{kva}_{\text{rated}} = \frac{(P_L+P_A)E_R{}^2}{1{,}000E_c{}^2} \times \frac{(C+D+E)N^2+X_A}{(A+B)N^2+R_A} \tag{21}$$

Current through inductor coil, I_L, amperes is

$$I_L = \frac{E_L}{N^2\sqrt{(A+B)^2+(C+D+E)^2}} \tag{22}$$

Capacitor voltage, E_c, volts is

$$E_c = I_L\sqrt{[N^2(A+B)+R_A]^2+[N^2(C+D+E)+X_A]^2} \tag{23}$$

Power dissipated in transmission line, P_A in watts is

$$P_A = I_L{}^2 R_A \tag{24}$$

Total power input at capacitor terminals (neglecting power loss in capacitor), P_T in watts, is

$$P_T = P_L + P_A \tag{25}$$

Limitations

For an accuracy of ± ten per cent the foregoing equations will apply in the range of the following limitations:

1. Single-layer solenoidal coil wound with rectangular conductor.
2. Cylindrical load telescoped in coil, coaxial with coil.
3. Length of load equal to or greater than length of coil with ends of load flush with ends of coil or extending out of ends of coil.
4. Ratio of inside diameter of coil to length $b_1/L \leq 1.0$.
5. Ratio of coil thickness to length $h/L \leq 0.07$.
6. Ratio of conductor wall thickness to inductor reference dimension $t_1/d_1 \geq 1.35$.
7. Inductor-coil space factor ≥ 0.70.
8. Permeability of coil and load material relative to a vacuum = 1.0.
9. Ratio of inside diameter of coil to reference dimension of coil $b_1/d_1 \geq 3.5$.
10. Ratio of outside diameter of load to reference dimension of load $a_o/d_2 \geq 2.0$.
11. Intercircuit capacitance negligible.

Coil Design and Use of Equations

Physical Dimensions

The length and diameter of the inductor coil are determined by the dimensions of the piece to be heated, the heat pattern desired, and the allowable clearance between inside of coil and outside of load. For a heating operation in which the piece or pieces of metal to be heated are fed continuously through the inductor, the length of the coil is determined by whether surface heating or through heating is desired and the amount of power utilized. For surface heating the coil is made short to realize high power densities, whereas for through heating a relatively long coil gives more satisfactory results. To minimize coil I^2R loss and required kilovolt-amperes of condenser, the inside diameter of the coil should be kept as small as possible. However, in the case of multiturn coils with a substantial potential difference between one end of the coil and the other, sufficient space must be allowed for an insulation coating between conductor and load piece, in addition to the necessary mechanical clearance. Also allowance must be made for expansion of the load when heated. The diameter of the load used in calculation should correspond to that at the particular load-material temperature used for load-resistivity determination.

The conductor wall thickness t_1 should be equal to or greater than 1.35 d_1 (d_1 is measure of current penetration) for effi-

Table III. Calculated Impedance Values Versus Experimental Results for Solenoidal Coils With Coaxial Cylindrical Loads of Nonmagnetic Materials at 10,000 Cycles Per Second*

			Case 1	2	3	4	5	6	7	8	9	10
Inductor, copper		Resistivity, ρ_1, microhm. inches	0.73	0.73	0.71	0.73	0.73	0.76	0.76	0.76	0.76	0.76
		Total turns, N	10	10	10	10	10	20	20	20	20	20
		Inside diameter, b_1, inches	3.010	3.010	3.010	3.010	3.010	1.127	1.127	1.127	1.127	1.127
		Length over turns, L, inches	3.0	3.0	3.0	3.0	3.0	5.95	5.95	5.95	5.95	5.95
	Conductor	Width, W, inches	0.252	0.252	0.252	0.252	0.252	0.248	0.248	0.248	0.248	0.248
		Height, h, inches	0.252	0.252	0.252	0.252	0.252	0.248	0.248	0.248	0.248	0.248
		Wall, t_1, inches	0.042	0.042	0.042	0.042	0.042	0.044	0.044	0.044	0.044	0.044
Load		Material	Copper	Brass	18-8	18-8	18-8	18-8	18-8	18-8	18-8	18-8
		Resistivity, ρ_2, microhm. inches	0.75	2.68	31.2	29.9	28.7	28.9	28.0	29.3	28.5	30.2
		Outside diameter, a_o, inches	2.500	2.500	2.500	1.005	1.001	1.005	1.001	1.000	0.625	0.375
		Wall, t_2, inches	0.131	0.034	0.133	0.135	0.061	0.135	0.061	Solid	Solid	Solid
Impedance values, ohms	Coil resistance, R_2	Calculated	0.0094	0.0094	0.0093	0.0094	0.0094	0.0074	0.0074	0.0074	0.0074	0.0074
		Measured	0.0091	0.0090	0.0090	0.0095	0.0093	0.0073	0.0073	0.0073	0.0073	0.0073
	Load resistance, R_s	Calculated	0.0057	0.0169	0.0485	0.0090	0.0122	0.0372	0.045	0.0290	0.0137	0.0032
		Measured	0.0056	0.0162	0.0455	0.0102	0.0121	0.0360	0.045	0.0280	0.0132	0.0029
	Total reactance, $X_2+X_s+X_o$	Calculated	0.148	0.148	0.170	0.328	0.333	0.071	0.090	0.0702	0.115	0.130
		Measured	0.144	0.143	0.165	0.316	0.326	0.0756	0.095	0.0755	0.119	0.133
Load reference dimension, d_2			0.0274	0.0518	0.177	0.173	0.170	0.170	0.167	0.171	0.169	0.174
Ratio, t_2/d_2			4.78	0.657	0.75	0.78	0.359	0.795	0.365			

* For further details see text.

cient heating. Generally, if the wall thickness is made less than 1.35 d_1, the coil losses will be increased.

Load Resistivity ρ_2

The resistivity of load material may vary considerably during the heat cycle. If the heat operation is of the continuous type, the required turns may be based on average values of load resistivity and out-

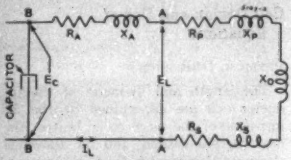

Figure 2. Equivalent electric circuit from capacitor through load

side diameter. If the load remains fixed in the coil during heating, separate calculations should be made for maximum and minimum temperature conditions. When the generator is to be loaded to its rated power output, then the greatest number of turns obtained should be used. This allows rated generator output at one end of the heat cycle without exceeding the generator rating at the other end of the heat cycle.

Conductor Resistivity ρ_1 and Coil Space Factor

The coil resistivity used in calculation should correspond to that at the actual operating temperature of the coil conductor. In determining the required turns it is necessary to assume some value of space factor. After the turns are calculated, a check should be made to find if the assumed space factor can be realized with available tubing. If not, a new calculation should be made on the basis of the obtainable space factor. Over the range of the prescribed limitations, greatest efficiency is obtained by making the space factor as close to unity as possible. In the case of multiturn coils with sufficient insulation for terminal voltages of 800 volts or less at 15,000 cycles or below, it is generally possible to realize a space factor of 0.80.

Selection of Frequency and Power Requirement

When the required power input to the load piece (based on past experience or a complete thermal calculation) is known, the necessary power input to the coil to produce this load power is found by dividing load power by efficiency of power conversion. This efficiency is given as follows when the appropriate expressions for A and B are substituted in equation 20:

$$\eta = \frac{1}{1+\frac{1}{3K_1^2}\frac{\rho_1}{\rho_2}\frac{b_1}{a_0}\frac{d_2}{d_1'}\frac{1}{K_2}} \qquad \left(\text{solid loads or } \frac{l_2}{d_2} \geq 2.0\right) \quad (26)$$

$$\eta = \frac{1}{1+\frac{1}{3K_1^2}\frac{\rho_1}{\rho_2}\frac{b_1}{a_m}\frac{d_2}{d_1'}\frac{1}{K_2}} \qquad \left(\text{hollow loads } 0.5 \leq \frac{l_2}{d_2} < 2.0\right) \quad (27)$$

$$\eta = \frac{1}{1+\frac{1}{3K_1^2}\frac{\rho_1}{\rho_2}\frac{b_1}{a_m}\frac{d_2}{d_1'}\left[\frac{l_2}{d_2}+\frac{4d_2^2}{a_m^2 l_2}\right]} \qquad \left(\text{hollow loads } \frac{l_2}{d_2} < 0.5\right) \quad (28)$$

where

$$d_1' = \frac{d_1}{1+d_1/b_1}$$

For most applications of induction heating the reference depth of the coil d_1 is small compared to the coil diameter b_1. Therefore d_1', is approximately equal to d_1, and for this condition the ratio of d_2/d_1' is nearly constant as frequency is varied. The only quantities which change appreciably with frequency in equations 26, 27, and 28, are K_2, K_3, and the expression in brackets respectively. Inspection and comparison of these equations will show:

(*a*). Where equation 26 applies power conversion efficiency increases with K_2 and therefore frequency (see Figure 5). In an analysis of efficiency and kilovolt-ampere requirements Stansel has advocated the use of frequencies at least sufficient to make[3]

$$\frac{a_0}{d_2} = 3.54 \qquad (29)$$

He points out, however, that there is no objection to higher frequencies, if economic factors warrant their use.

(*b*). Where equation 27 applies, power-conversion efficiency increases with K_2.

(*c*). Where equation 28 applies, power-conversion efficiency increases as the bracket expression decreases.

(*d*). Comparison of equations 26 and 27 and reference to Table I will show that for hollow loads with wall thicknesses less than 0.13 of the outside diameter greatest electric efficiency is realized by selecting a frequency to make K_2 maximum or to make the bracket expression of equation 28 minimum. This frequency is given approximately by

$$f = \frac{34.6\times10^4\rho_2}{a_m l_2} \qquad (30)$$

This is the frequency for minimum value of the bracket expression in equation 28 and corresponds very closely to the frequency for maximum K_2.

Coil Voltage E_L

The transmission-line impedance between capacitors and coil terminals should be kept relatively small for efficient power transmission. The effect of this impedance is to reduce the voltage E_L across coil terminals with respect to capacitor voltage E_c. In the solution of the foregoing equation for coil turns, E_L may be assumed to be equal to 0.9 E_c; then it usually will be economically feasible to design a transmission line to meet or better this condition.

Calculated Impedance Values Versus Experimental Results

In Table III a portion of the experimental results obtained is compared to calculated values in order to substantiate the use of equations 1 through 25 over the proposed range of limitations. All data given in Table III were obtained at 10,000 cycles per second (±0.5 per cent) with sinusoidal voltages and currents. All loads used in obtaining the data in this table were 18 inches long, located coaxial with the inductor, and extended through the inductor, so that ends of load were either flush with ends of coil or extending out of ends of coil. With the load extending out of both ends of the coil and then moved axially through the coil no change in impedance values was obtained up to the point where one end of the load was flush with the end of the coil. However, with further axial movement, such that the load did not extend fully through the coil, the impedance values changed. This condition of the load not extending fully through the coil represents a separate problem and is not considered in this paper.

Experimental impedance values were arrived at from voltage and current measurements made with thermocouple-type instruments. For this purpose the primary of the current transformer was

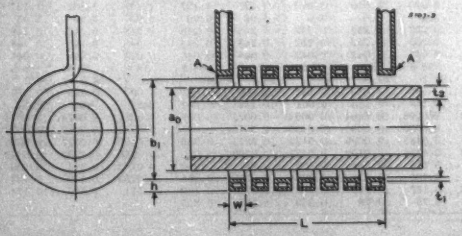

Figure 3. Inductor coil and load

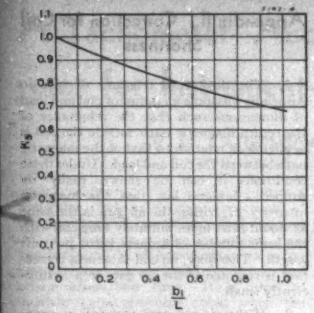

Figure 4. Nagaoka's constant K5

connected in series with the inductor coil (Figure 1), and the voltmeter was connected across AA. The total generator output was measured by a wattmeter connected at CC. This wattmeter was calibrated against thermocouple instruments for unity power-factor loads. The capacitor BB was adjusted so that the reactive volt-amperes measured at CC were negligible. The input to the coil was obtained by subtracting power losses in condenser and connectors from the generator output. These losses never exceeded 10 per cent of the output of the generator.

Where hollow loads were used, primary and secondary resistances were measured calorimetrically. Cooling water was circulated through the load and coil. Power dissipation was obtained by flow temperature-rise methods. Measured generator output less capacitor and connector losses was found to agree within ±3 per cent with measured power to the cooling water. In making resistance measurements where solid loads were used it was observed that:

1. Such loads could not be held at a constant low temperature, unless a surrounding water jacket were provided. This would make it impossible to separate coil and load losses where the air gap was small.

2. Direct calorimetric methods were therefore impracticable. However, the accuracy of the electrically determined input to the coil had been substantiated by experiments with hollow loads.

3. For the particular coil used in cases 6 to 10 (Table III) experiments with hollow loads had demonstrated that the nature of the load had little effect upon the resistance of the coil. Therefore, the total resistance of the coil with load inserted, R_2+R_t, was obtained from the electrically measured watts to the coil. R_t then was found by subtracting the value of R_2 measured for hollow loads.

The operating temperature of the load was determined by averaging thermocouple measurements over the conducting volume. The resistivity at this temperature was measured with a Kelvin bridge. The test sample was an open ring cut from a cylindrical section of the load. The ring was heated to the desired temperature in an oven.

Conclusions

1. The proposed equations apply over the given range of limitations with sufficient accuracy for calculating inductor coils for induction heating of nonmagnetic cylinders.

2. For hollow cylindrical loads with wall thicknesses less than 0.13 of outside diameter a definite frequency exists at which maximum power-conversion efficiency is obtained (see equation 30).

3. It is important to remember that the voltage across the coil is not necessarily equal to the generator output voltage due to the effect of transmission lines.

Appendix I. Expressions for Impedance—Hollow Loads

Units

Identical definitions apply to quantities previously defined, except that units in Appendix I are in the absolute or centimeter-gram-second electromagnetic system.

Consider a long solenoidal coil AA (Figure 1) wound closely about its load. The flux density on the outside of the load or in the air gap is

$$H=4\pi\frac{N}{L}I_L \tag{31}$$

Load With Wall Thickness Small Relative to Reference Depth

At any given time current density in the load may be assumed constant. Therefore, concentrated circuit theory applies.

Let

R_2 = resistance of load

$$=\frac{\pi a_m}{Ld_2}\rho_2 \text{ abohms}$$

X_2 = reactance of load

$$=2\pi f\left(\frac{4\pi}{L}\right)\left(\frac{\pi}{4}a_m^2\right) \text{ abohms}$$

X_M = mutual reactance between load and coil

$$=NX_2 \text{ abohms}$$

d_2 = reference depth

$$=\frac{1}{2\pi}\sqrt{\frac{\rho_2}{f}} \text{ centimeters}$$

The primary impedance associated with secondary current flux is:

$$\frac{X_M^2}{R_2+jX_2}=\frac{2\pi^2 a_m^2 N^2 f}{L}\times\frac{1}{\frac{R_2}{X^2}+j}$$

The primary impedance associated with primary current flux inside the load is:

$$j\,\frac{2\pi^2 a_o^2 N^2 f}{L}$$

Adding, the total primary impedance due to flux inside the load gives:

$$R_s+jX_s=\frac{2\pi^2 a_m^2 N^2 f}{L}\left[\frac{\frac{R_2}{X_2}-j}{\frac{R_2^2}{X_2^2}+1}+j\frac{a_o^2}{a_m^2}\right] \tag{32}$$

where

$$\frac{R_2}{X_2}=\frac{\rho_2}{2\pi^2 a_m f l_2}=\frac{2d_2^2}{a_m l_2} \tag{33}$$

When one converts this to the ohm-inch system and separates into real and imaginary parts, equations 2 and 4 are obtained, B and D being given by equations 13 and 14. (Under the assumptions of Appendix I, K_1 is unity.)

Loads of Intermediate Wall Thickness

The current density in the load is neither constant at any given time nor the same as for a solid load, at the same depth beneath the surface. Let

i = rms current density in abamperes per cm²

Φ = rms flux in maxwells

H = flux density in lines per cm²

r = distance from axis of load in centimeters

$k=2\pi\sqrt{2f/\rho_2}$

$x=\sqrt{jkr}$

o and I refer to outside and inside of load (except where subscript 0 denotes a Bessel function of zero order)

$r_m=\frac{1}{2}(r_1+r_o)$ centimeters

Consider an element of inside radius r, outside radius $r+dr$, and unit length, and apply Ohm's law. Then

$$2\pi\rho_2 ri+j2\pi f\Phi=0 \tag{35}$$

The rate at which flux density changes with radius is

$$\frac{dH}{dr}=-4\pi i \tag{36}$$

By definition

$$\Phi=2\pi\int_0^r rH\,dr \tag{37}$$

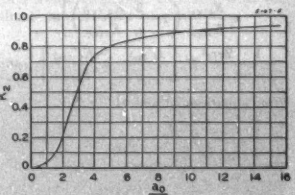

Figure 5. Load-resistance coefficient K2

Values of K_3 for $\frac{a_o}{d_2}>15$

$\frac{a_o}{d_2}$	K_3
30	0.97
100	0.99
∞	1.0

Differentiating equation 35 with respect to r and making use of equations 36 and 37 gives

$$\frac{d^2H}{dr^2}+\frac{1}{r}\frac{dH}{dr}-j\chi^2H=0 \qquad (38)$$

Equation 38 is a standard form of Bessel's equation of zero order.[4] The general solution is

$$H=C_1I_0(\chi)+C_2K_0(\chi) \qquad (39)$$

Where $I_0(\chi)$ and $K_0(\chi)$ are modified Bessel functions of zero order, of the first and second kinds. Substituting the boundary conditions for the inside radius into equation 35 and making use of equation 36

$$\psi(\chi_1)C_1+\phi(\chi_1)C_2=0 \qquad (40)$$

where

$$\left.\begin{aligned}\psi(\chi)&=-\frac{\rho\chi}{2}I_0'(\chi)+j2\pi^2f\mu^2I_0(\chi)\\ \phi(\chi)&=-\frac{\rho\chi}{2}K_0'(\chi)+j2\pi^2f\mu^2K_0(\chi)\end{aligned}\right\} \qquad (41)$$

Inserting the boundary conditions for the outside radius into equation 39 gives

$$H_0=I_0(\chi_0)C_1+K_0(\chi_0)C_2 \qquad (42)$$

Solving equations 40 and 42 for C_1 and C_2 and substituting into equation 39 gives

$$H=\frac{1}{1-m}\left[\frac{I_0(\chi)}{I_0(\chi_0)}-m\frac{K_0(\chi)}{K_0(\chi_0)}\right]H_0 \qquad (43)$$

where

$$m=\frac{\psi(\chi_1)K_0(\chi_0)}{\phi(\chi_1)I_0(\chi_0)} \qquad (44)$$

The total flux inside the rod is

$$\Phi_0=\pi r_1^2H_1+2\pi\int_{r_1}^{r_0}rH\,dr \qquad (45)$$

Integrating $I_0(\chi)$ and $K_0(\chi)$

$$\int rI_0(\chi)dr=\frac{r^2}{\chi}I_0'(\chi) \qquad \int rK_0(\chi)dr=\frac{r^2}{\chi}K_0'(\chi)$$

Therefore, from equations 43 and 45

$$\Phi_0=\frac{1}{1-m}\pi r_1^2H_0\left[\frac{I_0(\chi_1)}{I_0(\chi_0)}\left(1-\frac{2}{\chi_1}\cdot\frac{I_0'(\chi_1)}{I_0(\chi_1)}\right)-m\frac{K_0(\chi_1)}{K_0(\chi_0)}\left(1-\frac{2}{\chi_1}\cdot\frac{K_0'(\chi_1)}{K_0(\chi_0)}\right)\right]+\frac{1}{1-m}\cdot\frac{2\pi r_0^2}{\chi_0}H_0\left[\frac{I_0'(\chi_0)}{I_0(\chi_0)}-m\frac{K_0'(\chi_0)}{K_0(\chi_0)}\right] \qquad (46)$$

From equations 41 and 44

$$m=\frac{K_0(\chi_0)}{I_0(\chi_0)}\cdot\frac{I_0(\chi_1)-\frac{2}{\chi_1}I_0'(\chi_1)}{K_0(\chi_1)-\frac{2}{\chi_1}K_0'(\chi_1)} \qquad (47)$$

Therefore the first expression in brackets in equation 46 vanishes, leaving

$$\Phi_0=\frac{2\pi r_0^2H_0}{\chi_0}\cdot\frac{1}{1-m}\left[\frac{I_0'(\chi_0)}{I_0(\chi_0)}-m\frac{K_0'(\chi_0)}{K_0(\chi_0)}\right] \qquad (48)$$

The flux density at the outside of the load with unit current in the coil is $4\pi N/L$. The impedance of the coil associated with flux inside the load is $j2\pi fN$ times the corresponding Φ_0, or

$$R_2+jX_2=j\frac{16\pi^2fN^2r_0^2}{L\chi_0}\cdot\frac{1}{1-m}\times\left[\frac{I_0'(\chi_0)}{I_0(\chi_0)}-m\frac{K_0'(\chi_0)}{K_0(\chi_0)}\right] \qquad (49)$$

For sufficiently high values of χ the following approximations may be made:

$$I_0(\chi)=\frac{1}{\sqrt{2\pi}}\cdot\frac{e^{\chi}}{\sqrt{\chi}} \qquad K_0(\chi)=\sqrt{\frac{\pi}{2}}\cdot\frac{e^{-\chi}}{\sqrt{\chi}} \qquad (50)$$

Therefore:

$$\left.\begin{aligned}\frac{I_0'(\chi)}{I_0(\chi)}&=1-\frac{1}{2\chi}\approx 1\\ \frac{K_0'(\chi)}{K_0(\chi)}&=-1-\frac{1}{2\chi}\approx -1\end{aligned}\right\} \qquad (51)$$

Also, from equation 47

$$m\approx e^{-2(\chi_0-\chi_1)}\left(1-\frac{4}{\chi_1}\right) \qquad (52)$$

Substituting equations 51 and 52 into equation 49 and dropping terms in $1/\chi_1$ in the numerator gives

$$R_2+jX_2=j\frac{16\pi^2fN^2r_0^2}{L\chi_0}\times\frac{1+e^{-2(\chi_0-\chi_1)}}{1-e^{-2(\chi_0-\chi_1)}\left(1-\frac{4}{\chi_1}\right)} \qquad (53)$$

For loads with thin walls, equation 53 should agree with equation 32. Due to the approximations introduced by equations 51 and 52, this condition is more nearly satisfied if $4/\chi_1$ in the denominator is replaced by $4/\chi_0+4\delta/r_0$. An improvement in accuracy also results from the use of a correction factor r_m/r_0 for R_2. After these changes are made, equation 53 may be expressed

$$R_2=\frac{\pi a_m\rho_2N^2}{Ld_2}K_3 \qquad X_2=\frac{\pi a_0\rho_2N^2}{Ld_2}K_4 \qquad (54)$$

where K_3 and K_4 are, respectively, the real and imaginary parts of

$$(1+j)\frac{1+e^{(1+j)\frac{2t_2}{d_2}}}{e^{(1+j)\frac{2t_2}{d_2}}-1+\frac{8t_2}{a_0}\left(\frac{1-j}{2}\cdot\frac{d_2}{l_2}+1\right)} \qquad (55)$$

Appendix II. Correction for Coil Shortness

1. The theoretical relations derived in Appendix I assume an inductor coil and load of dimensions such that the reluctance of the return magnetic path outside the coil is negligible in relation to that of the magnetic path between the coil and load. Under these conditions it can be shown easily by Ampere's integral law that the magnetic intensity, H, within the air gap is the same as would exist in an infinitely long coil with the same number of ampere turns per unit length. Therefore, no coil-shortness correction is required if the air-gap area is sufficiently small.

2. If the air-gap area amounts to practically the entire area inside the coil (that is, if the space taken up by the load is negligible) the air-gap reactance is:

$$X_a=K_s{X_a}'$$

where ${X_a}'$ is the air-gap reactance which would be calculated by neglecting the reduction in flux density due to coil shortness, and K_s is Nagaoka's constant.[3]

3. The correction introduced in case 2 involves a reduction of $(1-K_s)$ of ${X_a}'$. The correction required in case 1 is zero. In intermediate cases it appears reasonable to subtract (air-gap area ÷ total area of coil) $(1-K_s)$ of ${X_a}'$. This gives

$$X_a={X_a}'\left[1-\left(1-\frac{{a_0}^2}{{b_1}^2}\right)(1-K_s)\right]=K_1{X_a}'$$

where K_1 is defined by equation 17.

While ${X_a}'$ is directly proportional to the air-gap flux density, H_a, the I^2R loss and time rate of change of magnetic energy in the load are proportional to H_a^2. Therefore, a coil-shortness correction of K_1^2 is required for R_2 and X_2.

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A Tachometer–Accelerometer–Vibrometer for Instrument-Gyroscope Testing

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Synopsis: This paper gives an account of the development, operating principles, and use of a possibly unique instrument that has been and is of considerable value on instrument-gyroscope manufacturing and repair production lines. It is used to indicate gyroscope-rotor speed when the rotor is brought up to 1,000 rpm for bearing adjustment. Then, by the turn of a switch, the instrument indicates the rate of deceleration as the bearing is adjusted, thus permitting accurate adjustment of bearing pressures. A third position of the same selector switch gives tachometer operation up to 15,000 rpm for vibration tests. Excessive vibration is indicated visibly and audibly through another amplifier, independently of the selector-switch position.

IN the manufacture of gyroscopic instruments for aircraft it has in the past been the practice to adjust the contact pressure of the ball bearings on which the rotor turns to a satisfactory working value by a coast test. At the point in assembly procedure at which this adjustment is to be made, the rotor is enclosed in a housing (in the case of the horizon gyroscope) as shown in Figure 1. The coast test was made by running the gyroscope up to substantially normal revolutions per minute as indicated by applied air pressure (occasionally checked by Strobotac), turning the air off, and measuring the coast time. This coast time was required to be between 8.5 and 13.5 minutes. This seems like a rather wide tolerance and in fact it was, but in spite of this it sometimes required several trials to get a proper adjustment.

A further objection to setting the bearings by clocking the coast times was the fact that rejections from the operation frequently ran as high as 50 per cent. As there were a number of other operations in the manufacture of gyroscopes that resulted in 50 per cent rejections this one did not seem outstandingly bad. Since some of the rejections were definitely caused by the burning or battering of the bearing surfaces by running at full speed with the rotor too tight or too loose, it seemed possible to improve the process by making the coast test from a lower speed.

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At lower speeds (as determined by operating air pressure) coast time was not a reliable measure of bearing pressure, evidently because the starting speed was not determined accurately. It was proposed that equipment be developed to measure the speed of the coasting rotor by determining the frequency of the tone generated by the buckets after the air supply had been shut off; two such measurements a minute apart would give an accurate measure of bearing pressure and save a great deal of time in making adjustments. This development resulted in a workable device, but it was subject to the disadvantages of a low sound level at low speeds and standing waves at high speeds.

A workable photoelectric system was also produced, using a photoelectric tube, amplifier, synchronous motor, and tachometer; a stroboscopic pattern on the rotor was visible through holes in the end of the casing (see Figure 1). There were objections to any method which required that the rotor of the horizon gyroscope be exposed. In the completed instrument the holes in the rotor housing were covered by a cap secured to the housing by four screws. Some manufacturers made bearing adjustments with a ring assembled to the housing in an attempt to reproduce any distortion of the case that would be caused by the final assembly with the cap, and thus eliminate the effect of this distortion on bearing adjustment.

Another possible solution to the problem was suggested by a hole in the rotor housing, intended eventually for the caging screw (filled during the coast test with a plug) through which a probe could readily be brought up close to the rotor buckets. By energizing this probe with several hundred volts of direct current through about two megohms resistance, the variation in electrostatic capacitance between the probe and the buckets as the rotor turned would cause a variation in the potential of the probe that could be impressed on the grid of an amplifier tube. This voltage variation was amplified, divided down in frequency[1] to the range of the synchronous motor and amplified further to run the motor; a tachometer driven by this motor was, in effect, geared to the gyroscope rotor.

First Acceleration-Measuring Model

Because it was the rate of change of rotor speed that was to be measured, and as there are a number of electric devices which are by their very nature such that they give a time differential, it seemed logical to measure this differential directly instead of measuring the speed at the beginning and end of a time interval.

It seemed desirable to start the coast at about 1,000 rpm, which would correspond to 60 cycles or 1,800 rpm for the synchronous motor to be used, and would allow over one minute of adjusting time before the speed dropped 50 per cent. The operation of the synchronous motor with the previously developed amplifier circuit was not reliable below 30 cycles. With a voltage change of two volts per minute from a standard tachometer magneto and with appropriate meters (which were not available), a meter–capacitor circuit would have given adequate results but there would have been something of a problem of adequately protecting the meter from severe overcurrents due to rapid speed changes.

Some 0–500 microammeters were available so an amplifier circuit was designed around these meters, and arranged to give a more expanded coast-time scale than would have been available with the direct-measurement system.

Figure 1. Bottom view of gyroscope-rotor assembly cut away to show rotor buckets and electrostatic probe

Figure 2. Front view of gyroscope test unit

This instrument is a combination tachometer, accelerometer, and vibrometer

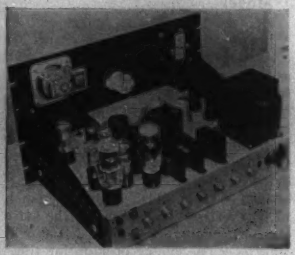


Figure 3. Chassis of gyroscope test unit showing calibration adjustments and test jacks

Figure 5. View of completion of bearing adjustment by coast test

This apparatus was developed and tested quite thoroughly. It was found practicable to set the coast time to within 0.5 minute of any desired value, and in the case of the horizon gyroscope this could be done in an over-all time of less than two minutes per instrument. Since the gyroscope was not run above 1,000 rpm until the bearings were properly adjusted it seemed reasonable to believe that the only rejections from such an operation would be those due to defective bearings. As nearly as it could be determined, the maximum error in deceleration measurements with this equipment was about 1.5 per cent. There was no error between the gyroscope and the synchronous motor, and the principle subsequent error was due to the voltage change on the regulated side of a constant-voltage transformer. See appendix for details of test method.

These results were so encouraging that it seemed certainly worthwhile to make some additional units, but it was found that certain items required a year for delivery. It was, therefore, decided to continue the development in order to eliminate the scarce items and reduce the size of the apparatus.

Final Model, Tachometer, Accelerometer, Vibrometer

It was found possible to obtain a pulsating unidirectional voltage having an average value that was linearly related to the speed of gyro rotor from an appropriate vacuum-tube circuit. Most of the pulsation was smoothed out in a resistance–capacitance filter, and the differentiating accomplished in the same way as when the direct current was supplied from a magneto. It was necessary to use substantially more circuit damping than in the earlier equipment, and in consequence the readings lagged behind the adjustment by an appreciable time, roughly two seconds. Other differences worth noticing were that the equipment was noiseless after the moving machinery had been eliminated, was less than half as large since it was also possible to eliminate several frequency-divider circuits, and the error in measuring decelerations was approximately twice as great as in the earlier model, but still of no consequence (at least in this application). Figure 2 shows a front view of this instrument, Figure 3 a view of the chassis.

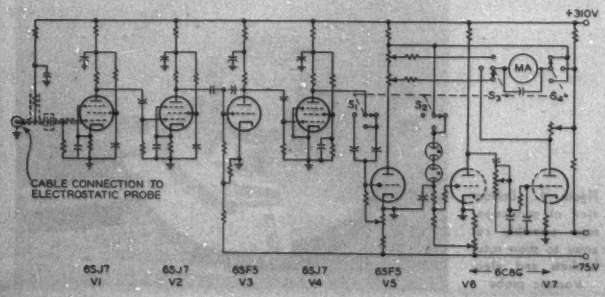
Circuit Details

As there are some elements of novelty in the circuit used, it will be described in some detail. The tachometer–accelerometer part of the circuit is shown in Figure 4, in which S_1, S_2, S_3, and S_4 constitute a four-pole three-position range switch, shown in the 1,000-rpm tachometer position. The central position is for coast test and the third position provides a 15,000-rpm tachometer.

There is a transient of perhaps 15 seconds duration associated with any abrupt change in the grid voltage of $V6$. Since $V6$ is concerned only with the coast test and the coast test is always preceded by use as a 1,000-rpm tachometer it is possible to eliminate this abrupt change, and with it most of the starting transient, by tying together the first and second positions of S_2 as shown.

Tubes $V1$ and $V2$ constitute a voltage amplifier with a gain of about 10,000. This permits satisfactory operation with the probe as much as 0.015 inch from the rotor. Tube $V3$ is a limiter and tube $V4$ is a clipper whose plate voltage is a square wave of bucket frequency, say 400 cycles per second at 1,000 rpm if the rotor has 24 buckets. The principal use of $V3$ is to keep the meter quiet when there is no input on the rotation channel. The capacitor from plate to grid of $V3$ (shown dotted) furthered this purpose. This

Figure 4. Schematic circuit diagram of tachometer–accelerometer circuits



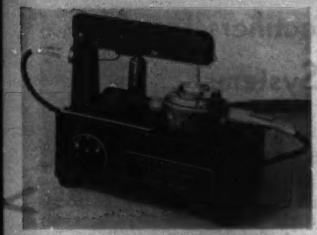


Figure 6. Horizon-gyroscope test fixture with vibration pickup in operating position

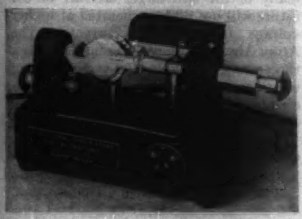


Figure 7. Test fixture for directional gyroscope

capacitor was very small and it has been found expedient to eliminate it by rearranging some of the wires.

Tube $V5$ is biased to cut off and coupled to $V4$ through a capacitance–resistance arrangement so that each stoppage of plate current of $V4$ causes a pulse of plate current in $V5$. This pulse of plate current in $V5$ is of such short duration that the average plate current of $V5$ is directly proportional to the speed of the gyroscope (over a wide range) and is read on a meter calibrated directly in revolutions per minute. Because the average plate current of $V5$ is proportional to the gyro rotor speed, the average voltage at the $V5$ plate will increase as the speed decreases, and speed versus average voltage will be linear. This average is an assumed average over a few cycles.

It is desirable at this point to be able to couple directly to the grid of the next stage and at the same time to reduce the magnitude of the voltage pulsation involved without losing any of the change in the average voltage. A glow-discharge device operating at low currents is essentially a constant-potential-drop device and furnishes a satisfactory coupling.[3] A capacitor in the grid circuit of $V6$ is a satisfactory first-averaging device.

Tube $V6$ is used in measuring deceleration as a voltage amplifier to magnify the change in average voltage and incidentally to reverse the direction of the change. A differentiating circuit is connected to the plate of $V6$ and the output of this differentiating circuit goes through a resistance–capacitance filter to the grid of tube $V7$. The plate current of tube $V7$ is then an inverse measure of the deceleration, so that longer coast times are indicated by higher deflections of the meter.

Advantage is taken of the curvature of the grid-voltage–plate-current characteristic of $V6$ to obtain a constant coast-time reading from the normally slightly decreasing deceleration. Since the plate voltage of $V5$ increases with decreasing rotor speed, the grid of $V6$ will accordingly become more positive. As the grid of $V6$ becomes more positive (within the normal operating region) the amplification factor increases. Therefore the normal gradual decrease in de/dt at the plate of $V5$ is considerably compensated for by a gradual increase in the amplification applied to the small changes in average voltage by $V6$. This results in de/dt at the plate of $V6$ being substantially constant during the useful part of the coast period (1,000 to 500 rpm).

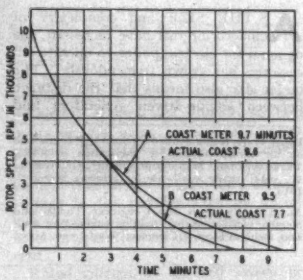


Figure 8. Coast curves of two directional-gyroscope rotors

Curve A is typical, and curve B exceptional on account of the shape at the lower end

The vibration circuit has not been shown as it consists only of a conventional audio amplifier and loudspeaker, with a $G10$ neon lamp that can be set to glow at any predetermined vibration level. The power supply has not been described because it is also entirely conventional.

Method of Use

In the actual operation of the equipment, for instance with a horizon gyroscope, the rotor assembly is placed in position so that air can be supplied to the inlet provided, and the cord is attached to the electrostatic probe that is already in place. The air valve is turned on with the range switch of the tachometer-accelerometer-vibrometer unit in the low position, and the speed is brought up to 1,000 rpm or slightly higher. Air is cut off and the range switch is turned to the coast position. The meter will swing off scale to the right and then come back to the appropriate coast reading in about five seconds. This reading will usually be too high or too low and it is necessary to loosen the bearing locknut, adjust the bearing, and reset the locknut before reading again. The meter will settle down on a new reading within a couple seconds after the locknut is reset. Figure 5 shows a picture taken after satisfactory adjustment. An experienced operator will usually have the proper bearing adjustment made by the time the rotor has slowed to 800 rpm and will then observe the constancy of the coast time reading for another 20 or 30 seconds. A slow random variation over a range of one minute or less is to be expected. A downward drift of as much as one minute is a definite indication of a defective bearing as will be explained later.

After the bearing tension is properly adjusted, the gyroscope may be safely operated at normal speed for vibration and bearing-noise test. For these tests a crystal pickup with a hardwood needle is dropped into position and lowered by a dash pot (Figure 6). Any vibrations are amplified by a conventional audio amplifier and reproduced by a loudspeaker. A neon lamp in the audio circuit can be set to glow when the vibration level is too high, thus making the test objective. The lamp adjustment is independent of the audio gain for the loudspeaker; the latter is controlled by a volume control on the front of the instrument.

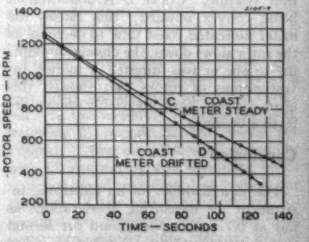


Figure 9. Low-speed coast curves for two gyroscopes

Curve C is normal, and curve D is abnormal, being convex upward. This is indicated on test by a pronounced downward drift in the coast reading

The use of the equipment in adjusting directional gyroscopes is to a considerable extent the same as that described above for horizon gyroscopes, but the holding fixture is different, as shown in Figure 7. In this case, both rotor bearings are adjustable so the rotor is held horizontally so that both are accessible.

The bearing tension is adjusted as before, and then the gyroscope is checked

for possible misalignment of rotor bearings by running the speed up to 2,000 or 3,000 rpm with the pickup in place. Misalignment to the extent usually encountered gives a recognizable rumble or beat in the loudspeaker and can nearly always be corrected by simultaneously adjusting both bearings to the right or left. After this correction it is necessary to readjust the bearing tension to the proper coast-time reading. After misalignment has been corrected, the vibration check at normal speed is made.

Performance Irregularities

In Figure 8 are shown coast curves of two directional gyroscope rotors. Curve *A* is typical of nearly all rotors, and shows the agreement between coast-meter reading and coast time that is usual. Curve *B* shows the performance of a (probably) defective assembly. The coast-meter readings were nearly the same and properly so since they were taken below 1,000 rpm where the curves are nearly parallel. It seems obvious that in such a case, the reading of the coast meter is a better measure of bearing pressure than the actual coast time.

Curve *C* of Figure 9 is in effect an enlargement of the low speed end of curve *A*, and shows normal performance in that the curve is convex downward. This corresponds to a slowly decreasing rate of deceleration. The circuit of the coast meter is so arranged as to compensate for this curvature and give a constant coast-time reading. Curve *D* is abnormal in being convex upward; this causes the meter indicated coast time to decrease as the rotor slows down, the change amounting to one or two minutes or more. Investigations of rotors that showed this characteristic have invariably shown defective bearings.

Conclusion

The practicability of an electronic instrument for measuring accelerations as low as 0.7 radian per second per second with instrument errors limited to a few per cent has been convincingly demonstrated by numerous installations, both in factory production lines and in field repair depots. There is no apparent reason why even smaller accelerations cannot be measured with greater accuracy if the need should arise, and by the present method. The instrument described has been entirely adequate for the present job.

Appendix. Deceleration Measurements by Coast Curves

As a check on apparent irregularities in coast-meter readings it was necessary to provide an independent method of measuring deceleration. This was accomplished by measuring time with a synchronous clock having a one revolution-per-second sweep, and measuring rotor bucket frequency with the Conn chromatic stroboscope.[3,4] The chromatic stroboscope is an instrument for measuring frequencies from 32 to 4,067 cycles per second by a stroboscopic method with a precision of ±0.05 per cent. This frequency range is in effect distributed logarithmically over a scale about 336 inches long. The error in reading a slowly varying frequency in the range of interest here is around 0.1 per cent since a stroboscopic pattern must be held stationary by slowly adjusting a variable-frequency tuning fork. The combined error in time and frequency measurements over a ten-second period is around two per cent but over a period of 100 seconds should be below 0.25 per cent.

Calibration

The factory calibration procedure is quite straightforward. The grid bias of *V5* is set at an appropriate value (about −8 volts) after a five-minute warm-up. Then the lower *V5* plate potentiometer is set so that on the 1,000-rpm range the meter reads 1,000 rpm with 400 cycles per second (five millivolts or more) input. The upper *V5* plate potentiometer is then set so that on the 15,000-rpm range the meter reads 10,000 rpm at 4,000-cycles per second (50 millivolts or more) input. This completes the speed calibration.

The coast calibration is made by adjusting the *V7* plate rheostat until the meter reads at a reference line (about 90 per cent of full scale) with no signal input. Then the *V6* grid bias is set to give −0.5 volt on the grid at 200 cycles per second input and checked for appropriate change at 400 cycles per second. Then the grid potentiometer of *V7* is set so that coast-time readings correspond to actual coast times for a number of gyroscopes.

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Selenium Power Rectifiers for A-C Aircraft Systems

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ASSOCIATE AIEE

Synopsis: Increasing electric-power requirements for large aircraft have brought about the introduction of a-c power systems. Two major systems have been developed. In the first power is generated at variable frequency and converted to direct current; in the second power is generated at substantially constant frequency, and both a-c and d-c power are used. In both systems selenium rectifiers can be used as converters. Rectifier units developed to supply 28.5-volt regulated d-c power, which include step-down transformers and voltage-regulating equipment, are described in this paper. Ratings vary from 100 to 800 amperes.

AS THE SIZE and complexity of modern aircraft have increased, the demand for electric power to operate accessories has grown tremendously. The larger size also means that the distance between engine-driven generators and their load has increased. When the 28.5-volt d-c power system is used, large heavy conductors are necessary to keep voltage drops within operating limits. To reduce conductor weight to a practical value and provide a more flexible power system, many of the still larger aircraft of the future will use power generated at higher voltage as alternating current.[1] The Army Air Forces have standardized on a three-phase 208-volt 400-cycle system, where constant frequency is used. Variable-frequency systems also are being considered for some applications.

Generation of power at 208 volts reduces the weight of conductors to a fraction of that required for 28.5-volt power.[2] Alternators are lighter and simpler than d-c generators of the same kilowatt output. With a-c generators brush problems are reduced, and, where simple induction motors can be used, motor brush troubles are eliminated.

Even with the constant-frequency system, where the fullest economical use can be made of alternating current directly, there is a definite need for appreciable amounts of d-c power. If batteries are used, they must be charged. Many in-

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Figure 1. Selenium-rectifier cell for aircraft use

Weight 1.75 ounces. Over-all size: 6 by 7 1/16 inches

struments now are designed to operate on direct current; with 28.5-volt d-c power available present designs of such instruments may be used, saving the time and man power required to develop new types.

If 28.5-volt control power is used, present low-voltage control switches can be used on crowded instrument panels. Some apparatus, although it can be designed to operate on alternating current, may be lighter or have more satisfactory operating characteristics if operated on direct current, for example, contactor coils.[3] In such cases the weight and efficiency of the apparatus required for both a-c and d-c operation must be determined. Then, before it is decided whether to use alternating or direct current, the cruising range of the airplane, the required duty cycle, and the amount of d-c power required for other applications must be taken into account.

To provide the required d-c power from the a-c system the selenium rectifier offers outstanding advantages. It does not have the high voltage drop of an electronic tube nor the moving parts and brushes of a rotating machine. It is simple, reliable, and easy to maintain. For three-phase power input a selenium rectifier can be designed for 85-per-cent efficiency. The weight of a complete unit including transformer and voltage-regulating equipment compares favorably with that of a motor generator set of the same rating.

Selenium rectifiers can be used with transformers to obtain any desired output voltage. Input may be single phase or polyphase. The widest present application is for 28.5-volt d-c units with three-phase input.

Selenium-Rectifier Cells

A selenium-rectifier cell is made by applying a thin layer of selenium to a base plate which is usually iron or aluminum. After heat treatment a low-melting-point alloy known as the "counterelectrode" is sprayed over the selenium surface. The resultant cell will permit current to flow freely from the selenium to the counterelectrode and block almost entirely the flow from counterelectrode to selenium. Characteristics of selenium-rectifier cells have been discussed thoroughly elsewhere.[2] Although special cells have been developed for aircraft use, they are manufactured in the same way and have the same general characteristics as commercial cells now on the market.

The weight of any apparatus for aircraft use is important. Since the heaviest part of the selenium cell is the base plate, this plate should be as light as possible. The size of the cell affects the over-all weight; a large size will reduce the dead weight of inactive areas and the necessary connecting hardware. Large cells also have lower leakage current per unit area. Size is limited by manufacturing facilities and mechanical considerations. Figure 1 shows a cell developed to meet aircraft requirements. This cell has 36 square inches of active rectifying area, the base plate is aluminum alloy 0.020 inch thick, and the finished cell weighs 1.75 ounces.

Current density in a selenium rectifier normally is limited by temperature rise and permissible aging when cooled by natural convection. With forced-air cooling, however, efficiency and voltage drop impose practical limits. As operating life for aircraft applications generally is 1,000 hours or less, aging is relatively unimportant. Tests have shown that to maintain a constant d-c output voltage of 30 volts, it is necessary to raise the a-c input voltage to the rectifier from an initial value of 26.8 volts to 27.5 volts after 1,200 hours of operation, an increase of 2.6 per cent.

Rated current of the cell shown in Figure 1 is 50 amperes d-c output from a three-phase bridge circuit for each cell in parallel per leg. This current density is considerably higher than that used for commercial rectifiers and is based on an adequate flow of cooling air. The voltage rating of a three-phase bridge rectifier is

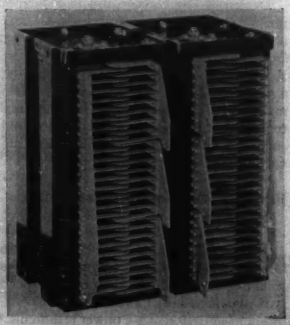


Figure 2. Selenium-rectifier stack assembly, rated 800 amperes 30 volts d-c output. Weight 35 pounds

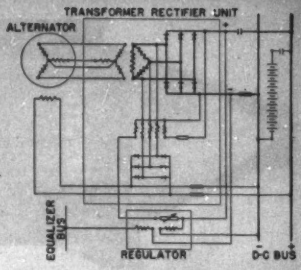


Figure 3. Diagram of variable-frequency power-supply system, showing alternator, transformer, main rectifier, field rectifier, saturable reactor, and voltage regulator

15 volts per cell in series. Higher-voltage rated cells have been produced but are difficult to manufacture, aging characteristics are less desirable, and ability to withstand overvoltage is not so good.

Selenium-Rectifier Stacks

Single rectifier cells act as "check valves" or half-wave rectifiers. For high efficiency a number of cells are connected in one of several possible circuits.[3] The three-phase bridge circuit is used most widely on three-phase power systems. It is simple to build mechanically, and only three connections are made to the a-c supply. If properly designed, a simple arrangement of connecting hardware can be used, and weight can be reduced to a minimum.

Figure 2 shows the three-phase selenium-rectifier stack assembly built for a unit rated 800 amperes 30 volts d-c output. In this assembly 192 cells are used, weighing 21 pounds or 0.87 pound per kilowatt. The complete stack assembly with all connecting and mounting hardware weighs 35 pounds or 1.46 pounds per kilowatt. Cells and connectors are assembled on insulated studs and held under pressure by nuts external to the end brackets. Elements are spaced to obtain maximum cooling effect with minimum air flow.

Cooling

The maximum design temperature of rectifier cells should not exceed 80 degrees centigrade. As Air Corps specifications call for operation in an ambient temperature of 60 degrees centigrade at sea level, sufficient air must be provided, either from the slip stream or a self-contained fan, to limit temperature rise to 20 degrees. Because of this low permissible rise, maximum volume of cooling air is required under sea-level conditions.

As the maximum operating temperatures of reactors, transformers, and fan motors are much higher than that of the

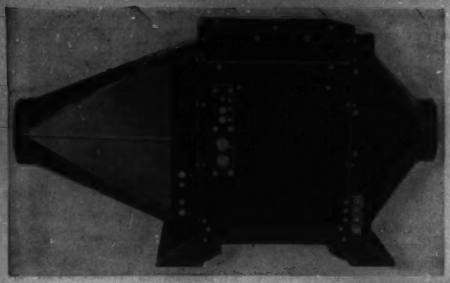
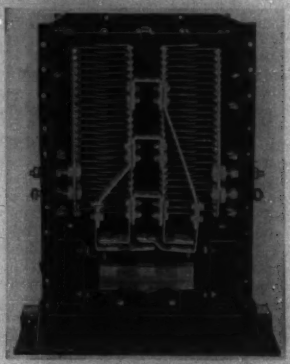


Figure 4. Complete rectifier unit used in variable - frequency system rated 800 amperes 30 volts d-c output

Figure 5 (below). Internal arrangement of rectifier stacks and transformer in rectifier unit of Figure 4



rectifier, the initial permissible rise is greater, and more cooling air generally will be required at high altitudes. Adequate air must be supplied to these auxiliaries to insure safe operation at the highest altitude for which the equipment is intended. With a constant volume of air through a fan-cooled rectifier the load on the fan motor decreases with altitude, so that requirements are less severe than those for a constant-load motor. For a given volume of air forced through the motor, however, a limiting altitude is reached beyond which it will overheat.

Selenium rectifiers have a negative temperature coefficient of resistance, and as the temperature falls the resistance increases.[3] The decrease in resistance of copper wiring and transformer windings partially compensates for this increase.[4] Operating temperature of the rectifier can be raised and resistance lowered under extreme low-temperature conditions by restricting the flow of cooling air. For large rectifiers to be used on high-altitude airplanes sufficient gain in efficiency may be made to justify the inclusion of automatic air-regulating devices.

Units with self-contained cooling fans are more satisfactory for operation within pressurized areas as blast-cooled units would require pressure-tight ducts and casings. There is some danger of damaging blast-cooled units by operating them on the ground with no cooling air available, unless air-flow protection is provided. Fan-cooled units with the fan motor connected directly to the input terminals eliminate this danger, as the motor will be energized at the same time as the rectifier. The major advantages of blast-cooled rectifiers are their lighter weight and the elimination of all moving parts.

Transformers and Reactors

In voltage-regulated power-rectifier equipments for aircraft transformers are used to provide the proper input voltage. Saturable core reactors connected in series with rectifiers and controlled by voltage regulators are used for voltage control. Both transformers and reactors for these applications use special core materials, and high-flux densities are permissible. They may be of the high-temperature type, with operating temperatures of over 200 degrees centigrade.[5] Copper conductors are cadmium-plated to prevent oxidation at high temperatures. Joints are silver-soldered. Glass fiber and glass tapes are used for insulation and impregnated with a special high-temperature resin. Forced-air cooling makes high-current densities possible.

Design of the reactor and transformer must be co-ordinated carefully with that of the rectifier and voltage regulator. Output-voltage variations are caused by changes in load, input voltage, frequency, and temperature. The saturable reactor must have sufficient range in reactance to permit the voltage regulator to hold constant voltage for extreme operating variation of the foregoing factors.

Rectifiers for Variable-Frequency Systems

If alternators are direct-connected to main engines, system frequency varies with engine speed. As the range of speed variation is usually more than two to one, direct application of a-c power is difficult.[6] Parallel operation of alternators is out of the question.

By furnishing a rectifier for each alternator and using direct current, all generating units can be made to feed power to the same bus. As far as distribution is concerned, this is a d-c system similar to those used at present. However, power is generated with alternators whose weight is a fraction of that of d-c generators of the same kilowatt output and is transmitted to the rectifiers, which may be located near the load center, at alternator voltage, reducing low-voltage wiring and bus work to a minimum.

Figure 3 is the diagram of a variable-frequency system in which all of the alternator output is rectified. All rectification, transformation, and voltage-regulating equipment except the voltage regulator proper are included in the casing shown in Figure 4. This includes step-down transformer, main power rectifier, saturable reactor for controlling alternator field current, and a field rectifier. Rated d-c output is 800 amperes 30 volts; input is three phase, 350 to 1,000 cycles, with maximum alternating voltage 250 volts. Combined efficiency of the transformer and main rectifier is 81 per cent at full load. Weight of the complete rectifier unit is 135 pounds, and the 32-kva alternator developed for this system weighs 50 pounds, a total weight for the system of 185 pounds or 7.7 pounds per kilowatt. This compares with a weight for engine-mounted d-c generators of 5.2 pounds per kilowatt. Obviously the alternator-rectifier system cannot be justified on the basis of weight of equipment alone. However, it should be noted that the alternator can be mounted directly on the engine, whereas a d-c machine of the same rating would be separately mounted, requiring additional weight for support. In addition, the saving in weight of conductors from generator to load center will be appreciable. With further development it is probable that the weight of the rectifier unit can be reduced considerably.

The voltage-regulating system is similar to that of a self-excited d-c machine in that field power is taken from the alternator output. As alternator field current is of the order of 50 amperes, it cannot be handled directly by a standard aircraft-type voltage regulator, and some type of

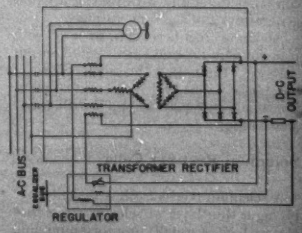


Figure 6. Diagram of rectifier unit used in constant-frequency system, showing saturable reactor, transformer, fan, rectifier, and voltage regulator

d-c current amplifier must be used. In this case the amplifier consists of a three-phase saturable core reactor in series with a three-phase bridge-connected selenium rectifier. Alternating current is supplied to the reactor input from the low-voltage side of the main transformer. The impedance of the saturable reactor varies with the current in its saturating coil which is controlled by a standard-type regulator. The output current of the saturable reactor is rectified and supplied to the alternator field. With this arrangement the voltage regulator controls currents up to ten times the current it can control directly. To make operation more stable a d-c damping winding is connected across the main rectifier output. An equalizing winding is provided on the regulator so that rectifiers may be paralleled, using the same scheme as that used with d-c generators.[7]

Under low-temperature conditions with the engine running at minimum speed, residual voltage may not be sufficient to cause the alternator to build up. This is due largely to the increased rectifier resistance at low temperatures, added to the field resistance and the impedance of the saturable reactor. To provide for positive build-up the field is connected across the main bus through current-limiting resistors. With the bus energized by a battery or other d-c source, sufficient field current will flow to initiate the build-up cycle. When the voltage of the field-supply rectifier reaches normal, current flow through these resistors is reduced to a negligible value.

The arrangement of transformers and main rectifier inside the casing is shown in Figure 5. To keep the center of gravity low, the transformer is mounted near the base. Cooling air flows in parallel paths through the transformer and rectifier. Automatic shutters regulate the flow of air through the rectifier stack; they are adjusted to begin to open when the temperature of the exit air from the rectifier reaches 50 degrees centigrade. At low temperatures, the gain in rectifier efficiency is considerable; by raising the operating temperature from 0 to 50 degrees centigrade, the efficiency is increased by six per cent. Air flow through the transformer is unrestricted. Cooling air is supplied from the slip stream and a pressure of six inches of water must be maintained at the air inlet.

Rectifiers for Constant-Frequency Systems

By maintaining a reasonably constant system frequency most of the generated power can be utilized as alternating current. If alternators are driven from the main engines a constant-speed coupling must be provided which will maintain proper alternator speed regardless of engine speed. Alternators may be paralleled.[8]

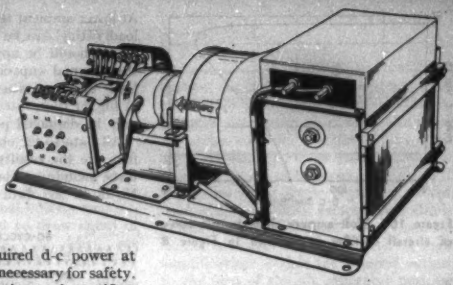


Figure 7. Aircraft rectifier unit for constant - frequency system, rated 200 amperes 30 volts d-c output

Note open construction, only rectifier and fan blade are enclosed

To furnish the required d-c power at least two rectifiers are necessary for safety. The number and ratings of rectifiers should be chosen so that all vital equipment taking power from the d-c bus can be operated with the largest unit out of service.

Figure 6 is the diagram of a unit designed for operation with the constant-frequency system. A saturable core reactor, transformer, rectifier, voltage regulator, and fan are included. For blast-cooled units the fan is omitted. Output voltage is controlled by a standard aircraft-type voltage regulator and a saturable reactor. In general, the regulating system is the same as that of the 800-ampere unit, but in this case the entire rectifier output is controlled instead of alternator field current. An equalizer winding is provided on the regulator to permit parallel operation of rectifiers. The voltage regulator is separately mounted and can be located at any convenient point.

In Figure 7 is shown a transformer rectifier unit rated 200 amperes 30 volts d-c output designed to take three-phase power from a 208-volt 400-cycle system. Cooling air is supplied by a magnesium-alloy fan mounted on the shaft of a 7,600-rpm induction motor. This unit will operate under all conditions encountered from a 60-degree-centigrade ambient temperature at sea level to an altitude of 40,000 feet. To save weight no enclosing case is used. The fan is located inside the air duct extending from the rectifier stack and discharges air over its driving motor to the transformer and reactor. Weight complete is 47 pounds.

Another unit developed for the constant-frequency system is shown in Figure 8. It is rated 100 amperes 30 volts d-c output, is blast-cooled, and requires an air pressure of three inches of water at the inlet. All parts except the voltage regulator are mounted inside the casing; the compact arrangement of parts is shown in Figure 9. Over-all dimensions are $6\frac{1}{2}$ by $6\frac{1}{4}$ by 26 inches, and weight is 28 pounds.

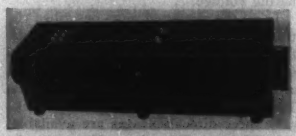


Figure 8. Aircraft rectifier unit for constant-frequency system rated 100 amperes 30 volts d-c output

Cooling air supplied from external source

Operation

Operating characteristics of these saturable-reactor-controlled rectifier units are similar to those of a d-c generator. They have a drooping volt-ampere characteristic due to the regulation inherent in the reactors, transformers, and rectifiers. As load increases, the voltage regulator keeps output voltage constant by increasing saturating current in the reactor. After the saturating current has reached its maximum value, further increase in load will reduce output voltage. This, in turn, reduces saturating current, lowering still further the output voltage. The result is that a critical point is reached beyond which operation becomes unstable and the voltage breaks down. In the case of the variable-frequency system, short-circuit currents are low, as the a-c supply voltage also breaks down. Constant-frequency units, on the other hand, have short-circuit currents of the order of 150-per-cent load current if a-c input voltage is maintained. Current in this latter case is

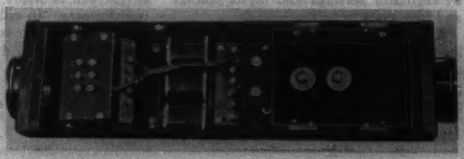


Figure 9. Aircraft rectifier unit, same as Figure 8

Cover removed, showing compact arrangement of parts

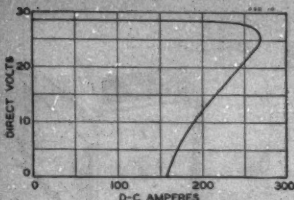


Figure 10. Volt-ampere characteristic curve of aircraft rectifier unit shown in Figure 8

limited primarily by the maximum reactance of the saturable reactor.

Figure 10 shows the volt-ampere characteristic of the 100-ampere unit of Figure 8, with the voltage regulator set to hold 28.5 volts. Input voltage and frequency are held at normal values. Short-circuit current under these conditions is 160 per cent and maximum current 270 per cent of rated value. The effect of a short circuit applied with the same rectifier carrying rated load current and the regulator set to hold 30 volts is shown in the oscillogram of Figure 11. Instantaneous peak current was 411 per cent which decayed to a steady-state value of 165 per cent in $^1/_{30}$ of a second. Instantaneous peaks as high as 600 per cent have been noted under no-load initial conditions. The values of peak and steady-state currents depend on alternating voltage, frequency, load, and regulator setting.

Maximum load and short-circuit currents are increased if a separate source of reactor-saturating current is provided. The volt-ampere characteristic then resembles that of a separately excited d-c generator. For the constant-frequency system this source of current may be a small "exciter" rectifier.

A "compounding" series winding may be added to the saturable reactor through which all or part of the output current flows. By proper design any degree of compounding may be obtained. Compounding reduces the required resistance range of the voltage regulator but adds to the weight of the reactor and complicates the wiring.

Division of load between units, even those of different ratings, is satisfactory. Figure 12 shows the load division between the 100-ampere and 200-ampere units of Figures 7 and 8 under conditions of normal voltage and frequency. The division will vary somewhat, depending on regulator settings and input voltage and frequency.

All of the units described can be overloaded for a short time. With maximum ambient temperature for which the apparatus is designed they are rated at 150-per cent normal current for three minutes. At lower ambient temperatures this overload rating can be increased. All overloads should be applied with caution as the thermal capacity of the rectifier is low. These units never should be operated at higher than rated voltage, or the cells may be damaged permanently.

All data so far obtained on these rectifiers are the results of extensive ground tests, including tests in altitude chambers. No flight-test data are as yet available,

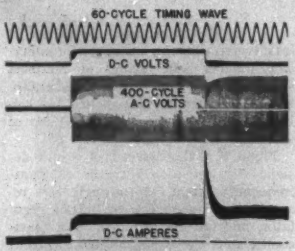


Figure 11. Oscillogram of short circuit applied to rectifier unit shown in Figure 8

Regulator set to hold 30 volts. Rectifier was carrying rated load when short circuit was applied

but it is expected that thorough flight tests will be made in the near future.

Applications of Unregulated Rectifiers

For some applications where the d-c load is substantially constant it may be practical to use selenium rectifiers without voltage regulation. Such rectifiers may be designed to operate directly from the a-c line or with suitable transformer to provide any desired direct voltage. Variations in direct voltage will be only slightly greater than those of the system alternating voltage.

In all the regulated units described the transformer weighs more than the rectifier stack, so that the use of rectifiers operated directly from the a-c lines offers attractive weight-saving possibilities. This scheme has one serious drawback; only three direct voltages are available, 220, 170, and 100 volts. These are obtained by the use of a three-phase bridge-connected rectifier, a single-phase bridge connected line to line, and a single-phase bridge connected line to neutral, respectively. Some saving in transformer weight can be made by the use of auto-transformers. In either case the d-c circuit is electrically connected to the a-c lines, and neither d-c terminal can be grounded if the a-c system is grounded at any point.

In any case where the rectifier supplies

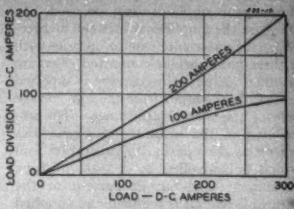


Figure 12. Distribution of load between rectifier units shown in Figures 7 and 8

Rectifiers paralleled through 0.5-volt dropping resistors. Regulators set for 30 volts

a fixed load no d-c switch is necessary. The rectifier may be connected permanently to its load and all switches, contactors, and protective devices located in the a-c line.

Conclusion

It must be kept in mind that the selection of an electric-power system is an individual problem for each airplane. The size of the airplane, its ceiling, its maximum cruising range, and its purpose all must be considered. Power requirements for a cargo airplane, a passenger airplane, and a bomber will differ widely even when all are the same size and general design. Larger airplanes of all classes are being considered for the future, and many of them will have auxiliary power generated as alternating current. In most cases considerable amounts of d-c power still will be required, and in supplying this power the selenium rectifier will find a wide field of application.

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Static Voltage Regulator for Rototrol Exciter

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THE CONCEPT of a generator voltage regulator as an amplifier which produces a large correction in field current for a small departure from normal voltage is quite well known.[1] In the conventional regulator, such as a direct-acting type, this amplification is secured partly in the regulator and partly in the exciter. A rotating amplifier-type regulator provides the amplification almost entirely in the rotating machines. Exciters may be used to obtain two or more stages of amplification, or a single machine having high amplification such as a Rototrol exciter may be used. An example of two-stage excitation is a system with the regulator working in a pilot exciter field.

With high amplification available in the excitation system, voltage regulation can be secured by arranging the control field of the exciter or Rototrol[2] to raise or lower in response to any deviation of generated voltage from the standard of reference.

The particular Rototrol referred to in this paper is a d-c generator operated on the linear part of its saturation characteristic and completely self-excited by shunt and series fields. As such, it will support itself at any voltage from zero up to the point of saturation. It has one or more control fields which run it up or down in voltage as required and keep it operating stably at any desired point.

The present development was undertaken on the basis that a battery could not be used for the standard of reference and that the voltage reference must be inherent in the circuit. Also vacuum tubes could not be used; there must be no moving parts except for the rotating machines, and these should have air gaps approximately as large as in conventional d-c generators.

The choice of voltage reference was narrowed down to "intersecting impedance characteristics." This is the general name given to circuits that detect and respond to voltage level in the following manner. At normal voltage two impedances are adjusted to draw equal or proportional currents; at least one impedance is nonlinear. At higher voltage one impedance draws more current than the other, and the difference current is in a direction indicating voltage above normal. It can be used for control. At lower voltage the same impedance draws less current than the other and the difference thus is reversed, indicating voltage below normal. The currents are rectified before comparison.

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Static Voltage-Regulating Circuits

A static type of circuit for the purpose of regulating the voltage of an a-c generator has been used previously,[3] a three-core saturable reactor being employed for amplification as part of the static circuit. Similar circuits using Rototrols for the amplification are illustrated in Figure 1.

The voltage-measuring circuit of Figure 1A consists of a resistor path I_R and a saturating-reactor path I_X, with the current in each path rectified and fed into the control fields of the Rototrol. This illustrates a circuit using a Rototrol pilot exciter, an exciter of conventional design, and an a-c generator. The Rototrol control fields are connected to be equal and opposite magnetically, when the a-c generator voltage is normal at the regulated value. Under this condition the Rototrol output voltage is maintained at the required value by its self-energizing shunt and series fields. If the alternating voltage rises or falls, the control fields adjust the Rototrol as needed to restore normal voltage.

Figure 1B shows the intersecting impedance characteristics, R for the resistor circuit, and X for the reactor circuit. In regulating circuits of this kind means are provided for raising or lowering the point of intersection or "normal" voltage, to allow adjustment of the value which the regulator is set to maintain. Figure 1C shows the same static regulator except used with a Rototrol exciter, thus eliminating the pilot machine. The Rototrol exciter is designed to have relatively high amplification, so that the required output to the field of the a-c generator may be controlled by a small amount of energy in the control field.

Other static circuits are shown in Figure 2. The generator terminal voltage is balanced against a reference voltage, and the differential which appears when the generator voltage deviates from normal is applied to the Rototrol field or fields. For the reference voltage a separate source either direct or alternating current may be used, or, if none is available, a constant potential device may be employed, energized by the voltage of the generator with which the regulator is used. This device is designed to provide essentially constant alternating voltage on its output terminals in spite of relatively large changes in its input voltage.

Figure 2A shows a static regulator controlling a Rototrol exciter which has two control fields. These are connected to have equal and opposite magnetic effect when the a-c generator voltage is at the desired normal value. Should load be added to the generator, thus causing drop in the terminal voltage, the "raise" field predominates and raises the Rototrol armature voltage thus restoring the alternating voltage to normal. The Rototrol control fields again reach a balance.

Figure 2B shows a balanced-voltage circuit arranged to feed a single control field. In this case the control field normally has no current flowing through

Table I. Sample Calculation of E_I/E_R versus E_x/E_R

Refer to Figure 6

These Calculations Are for the Case, $R' = 0.2R$ and $R_f = 0.3R$

$E = 1.00$, $E_{eq} = \frac{R_f}{R+R_f} = 0.2308$ $\qquad$ $R_{eq} = \frac{RR_f}{R+R_f} = 0.2308R$, $\frac{R_{eq}}{R'+R_{eq}} = 0.534$

1	2	3	4	5	6	7
θ	$E_x = \sin\theta$	$E_d = \cos\theta$	$E_R = \frac{E_d + E_{eq}}{E_d + 0.2308}$	E_x/E_R	$E_I = \frac{R_{eq}E_R - E_{eq}}{R'+R_{eq}} = 0.534E_R - E_{eq}$	E_I/E_R
0	0	1.0000	1.2308	0	0.428	0.347
10	0.1736	0.9848	1.2156	0.143	0.419	0.347
20	0.3420	0.9397	1.1705	0.292	0.395	0.337
30	0.5000	0.8660	1.0968	0.456	0.355	0.324
40	0.6428	0.7660	0.9968	0.645	0.302	0.303
50	0.7660	0.6428	0.8736	0.878	0.235	0.269
60	0.8660	0.5000	0.7308	1.186	0.160	0.219
70	0.9397	0.3420	0.5728	1.640	0.0752	0.131
80	0.9848	0.1736	0.4044	2.432	−0.0148	−0.0366
90	1.0000	0	0.2308	4.333	−0.1076	−0.466

it. By reason of this, it is evident that there are no losses and no heating in this field so long as the a-c generator voltage remains at the normal regulated value. This permits using a minimum of material in the frame of the Rototrol, as winding space and winding losses are less than in the case where continuously energized equal and opposite control fields are employed.

Requirements of New Regulating Circuit

In the development described in this paper, generators having ratings exceeding 1,000 kva at 1,200 rpm were to be controlled, and conventional exciter air gaps were desirable for mechanical reasons. This fixed the control-field energy requirements. Previous designs of static regulators such as described hereinbefore would have been excessive in size and losses, had they been designed to provide adequate control power. It became necessary to make a thorough analysis of the design of such devices to secure optimum energy output for a given voltage departure from normal.

Average three-phase (or positive-sequence) voltage response was required. This further increased the energy requirements, as the positive-sequence network size must be adequate to carry the larger power of the measuring circuit. This problem was solved by deducting negative-sequence voltage from line voltage rather than filtering positive-sequence voltage directly in the conventional manner.

Considerable error in regulated voltage due to frequency was tolerated on earlier static regulators. In the new development it was desired to regulate closely for the same voltage level over a plus- or minus-five-per-cent departure from normal frequency.

To meet these requirements a static regulator of high efficiency was devised. Figure 3 shows a regulator of this type. The following paragraphs describe this regulating network and give its theory and performance.

Circulating-Current-Type Static Network—Theory

One arrangement of the circulating-current type of static-regulating network is shown in Figure 4A. A saturating reactor and resistor are used for the nonlinear and linear branches, respectively. The voltage gradient may be viewed as shown in Figure 5. At normal voltage the voltage drops in the resistor, KR, and reactor, X, are equal and the control-field voltage is zero, as in Figure 5B. As the input voltage is raised or lowered, the saturating-reactor voltage remains nearly constant and the control-field voltage becomes positive or negative, respectively. This is shown in Figures 5A and 5C.

Performance Calculation

Calculations were made to determine the most efficient design of this type of network. First it was necessary to develop a method of calculating the power output from the network as a function of the parameters X, R, R', and R_f of the network and connected control field of Figure 6. Also, a method was developed for the calculation of the direct voltage on the rectifiers to determine whether R' and $(1-k)R$ were large enough to keep both rectifier voltages positive over the necessary range of operation (usually for a plus- or minus-ten-per-cent departure from normal line voltage).

Calculations then were made using these methods to determine the relative values of the parameters X, R, R', and R_f which would produce optimum control-field input power as a function of line-voltage departure from normal, with minimum energy consumed in the network itself.

This method of calculation assumes pure sine-wave currents and voltages in the a-c circuits and smooth direct current in the d-c circuits. It is recognized that the actual wave shapes are considerably distorted and that an empirical factor determined from test must be used to allow for this difference. This factor was found to be of the order of 0.5 in field current. The analytical method used with this empirical factor serves as a very satisfactory basis of direct design. The method also affords valuable insight into the operation of the network and a close approach to optimum efficiency which then can be further refined by experimental work.

Method of Calculation

The problem may be stated as follows:

Given the saturation curve of the reactor X, such as Figure 7, and the values of R, R', and R_f.

Required to determine field voltage, E_f, as a function of the applied line voltage.

The network of Figure 6A contains a-c and d-c circuits and a nonlinear element, and hence, cannot be solved by conventional methods of analysis.

The saturating reactor can best be treated by assuming a value of current, reading the corresponding voltage from the saturation curve, and then calculating the currents and voltages throughout the balance of the network.

As the alternating voltages being dealt with are about to be rectified in single-phase full-wave rectifiers, it is convenient to use their average rather than their rms magnitudes. Then no factor need be applied when passing from alternating to direct current through the rectifier.

Figure 6C shows a vector diagram

Table II. Sample Calculation of Field Power From Static Regulating Network

Refer to Figure 6A

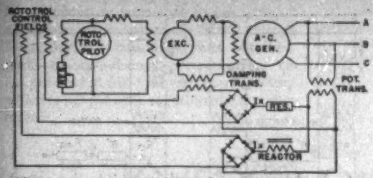
The Subscript n Denotes the Value of a Quantity at the Normal Regulated Voltage Condition. Calculation Based on: $R'=0.2R$ and $R_f=0.3R$

Let $E_{zn}=1.000$ $I_{zn}=1.000$ $X_n=1.000$ $E_n=E_{zn}/\cos\sin^{-1}\frac{R'}{R}=E_{zn}/0.98=1.02$ $R=E_n/I_{zn}=1.02$, $R'=0.204$, $R_f=0.306$

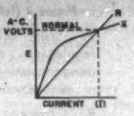
$P_n=E_nI_{zn}=\frac{R'+R}{R}=1.02\times1.00\times1.20=1.224$ $R_{eq}=\frac{R_f}{1+R_f/R}=\frac{0.306}{1.300}=0.2354$ $R'+R_{eq}=0.4394$

$E=\frac{R}{R'+R_{eq}}E_B-\frac{R}{R_{eq}}E_f=2.320E_B-4.33E_f$

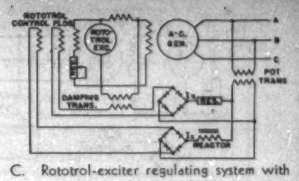
1	2	3	4	5	6	7	8	9	10	11	12
E_a	I_z (Figure 7)	$E_B=I_z(R'+R_{eq})=0.4393I_z$	E_a/E_B	E_f/E_B (Figure 8)	$E_f=$ (3)×(5)	$E=2.320E_B-4.33E_f$	E/E_a P.U. Line Voltage	$P_f=E_f^2/R_f=E_f^2/0.306$	P_a Per Cent Field Power	$\frac{100}{(10)}\left[\frac{1-(8)}{0.1}\right]^2$	$\frac{E_f}{E_a}$
0.890	0.467	0.2054	4.33	−0.486	−0.0958	0.890	0.872	0.0299	2.440		0.0937
0.918	0.558	0.2440	3.75	−0.334	−0.0818	0.920	0.902	0.0217	1.770	54.3	0.0800
0.950	0.707	0.3110	3.06	−0.178	−0.0554	0.961	0.942	0.0100	0.820		0.0538
1.000	1.000	0.4394	2.28	0.	0.	1.020	1.000	0.	0.		0
1.025	1.189	0.5225	1.960	+0.064	0.0334	1.069	1.048	0.00365	0.298		0.0328
1.050	1.414	0.621	1.690	+0.119	0.0739	1.121	1.100	0.01785	1.458		0.0725
1.075	1.683	0.739	1.455	+0.160	0.1180	1.188	1.165	0.0455	3.73		0.1160



A. Rototrol-pilot-exciter regulating system



B. Intersecting impedance characteristics



C. Rototrol-exciter regulating system with opposed control fields

Figure 1. Static voltage regulators using intersecting impedance characteristics

which is a convenient representation of the complete circuit. To understand it, note first that Figure 6A can be simplified to Figure 6B using Thevenin's theorem.[4] The values of E_{eq} and R_{eq}, in terms of E, R, and R_f are shown by the equations in Figure 6. Note that in the d-c circuit of Figure 6B, the voltage drop across R' and R_{eq} in series is the numerical sum of E_d and E_{eq}. Also note that E_d is obtained from E by subtracting the I_zX drop vectorially from E. The current I_z must be in phase with E_d as the circuit below E_d in Figure 6B appears as pure resistance or in phase. Hence, the drop I_zX must be at right angles to E_d, and this fixes the form of the vector diagram Figure 6C. Note that the relationships in the d-c part of the circuit all are treated as though in phase.

If we start with the current I_z, the voltage E_z is readily determined from the saturation curve, Figure 7. E_R is obtained by multiplying I_z by $(R' + R_{eq})$. E is known and E_{eq} determined from the equation in Figure 6. It remains to find the field voltage, E_f. This can be done most easily by letting θ vary and calculating E_z/E_R and E_f/E_R for various values of θ, and plotting E_f/E_R as a function of E_z/E_R as shown in Figure 8. From these curves the value E_f/E_R and then E_f readily can be determined. A derivation and sample calculation of these curves for $R' = 0.2R$ and $R_f = 0.3R$ is given in Appendix I. Figure 8 gives curves for $R' = 0.2R$ for various values of R_f.

A derivation and sample calculation also is given in Appendix II for field input voltage and power as a function of the departure of line voltage from normal. Figure 9A shows field power and voltage as a function of line-voltage deviation from normal, for the range of operation in which the rectifier voltages are above zero. Figure 9B shows the field power over an extended range of line voltage drop. Another curve, Figure 10, has been drawn for various values of R_f and R', giving watts input to the network per watt input to the field, for a ten-per-cent a-c line voltage drop. This curve is based on several calculations similar to Table II of Appendix II. It indicates that the best performance is obtained with $R' = 0.2R$ and $R_f = 0.3R$. However, the field resistance, R_f, may be varied 40 per cent from this value without reducing the control-field input, at ten-per-cent voltage drop, more than 20 per cent.

A capacitor or a linear inductance may be substituted for the resistor to form the linear branch. The capacitor has the advantage of minimum power loss and correction of power factor, which reduces the required size of potential transformers and compensators.

The foregoing analysis applies equally well whether the impedance kR consists of a resistor, capacitor, or linear reactor having the same ohmic value. With the assumption of smooth direct current, phase relationships are not reflected through the d-c circuit. If the branch, kR, is a capacitor or a reactor, the curves of Figure 10 should be interpreted as giving the summation of volt-amperes (arithmetic sum) in branches, R', $(1-k)R$, and kR, per watt in the control field.

It may be more significant in this case to give the *total* network volt-amperes (arithmetic sum of volt-amperes in each part) per watt in the control field. This can be done by substituting the total volt-amperes for P_n in Table II. The summation of network volt-amperes is given by

$$P_n' = E_n I_{zn} \frac{R'+R}{R} + 1$$

For the example worked out in Table II, P_n' would be 2.224 and the network volt-ampere scale would be 2.224/1.224 times the network watt scale of Figure 10.

The summation volt-amperes as used in the foregoing are of significance chiefly in providing a measure of size of the network. The volt-amperes drawn from the source also are important in determining the design of the potential transformer, sequence network, compensator, and so forth, through which this burden is drawn. The input volt-amperes may be obtained by vector addition of the volt-amperes of parts. Use of a capacitor for the linear branch then largely offsets the saturating-

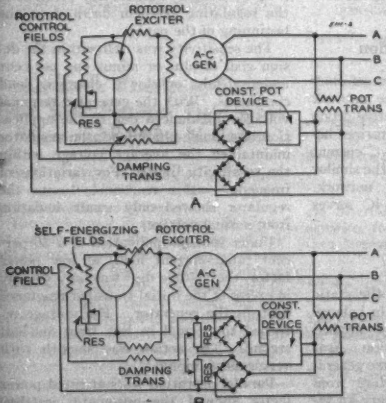


Figure 2 (left). Static voltage regulators using fixed reference potential

A. Opposed control fields

B. Balanced-voltage network and single control field

Figure 3 (right). Static-Voltage-Regulator units

A—Potential and compensator unit

B—Voltage-regulator unit

C—Voltage-adjusting rheostat

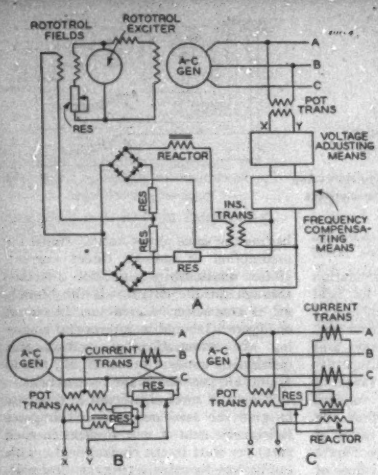


Figure 4 (left)

A. Static voltage-regulating system using circulating-current network

B. Conventional positive-sequence network and reactive-droop compensator

C. Current-energized sequence network including reactive-droop compensation

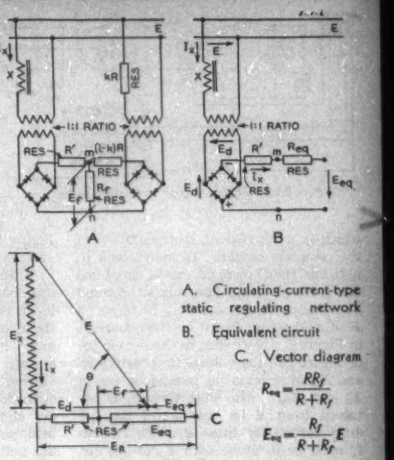


Figure 6 (right)

A. Circulating-current-type static regulating network

B. Equivalent circuit

C. Vector diagram

$$R_{eq} = \frac{RR_f}{R+R_f}$$

$$E_{eq} = \frac{R_f}{R+R_f} E$$

reactor volt-amperes at the normal regulated voltage and minimizes the input volt-amperes to the measuring circuit.

Positive-Sequence Response

The static-regulator volt-ampere parts are determined by the power requirements of the control field as outlined in the foregoing section. In the present development this burden proved to be much larger than the normal burden of a conventional regulator element. In order to provide positive-sequence response the regulator current in the past has been drawn through a positive-sequence network or filter.[5] However, this device increases in size directly with the burden supplied through it; consequently, some other plan for obtaining positive-sequence response was needed.

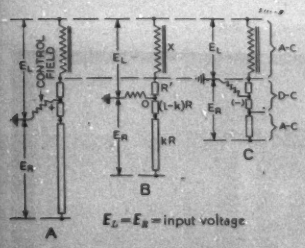


Figure 5. Approximate voltage gradient in circulating-current-type static regulating network

A—Overvoltage—control-field voltage positive

B—Normal voltage—control-field voltage zero

C—Undervoltage—control-field voltage negative

The positive-sequence voltage can be derived by subtracting the negative-sequence voltage from line voltage. This is accomplished by passing the secondary currents of the current transformers through a network proportional to the negative-sequence impedance of the generator. The derived negative-sequence voltage then is deducted from the line voltage. The previously used voltage filter and the new current filter are indicated in Figures 4B and C, respectively. The remainder of the regulating circuit is the same in either case and is as shown in part A. The current-energized sequence filter required about $^1/_{10}$ of the volt-amperes of parts as compared with the voltage-type sequence network of Figure 4B. Tests showed it to be accurate and reliable. One potential and two current transformers are used in place of two potential transformers and one current transformer.

Reactive-Droop Compensation

With the single potential transformer and current-energized sequence network shown in Figure 4C, the reactive-droop compensator for parallel operation becomes a resistor in the phase-*C* current and thus can be combined with the similar resistance of the sequence network. Thus, the resistor in Figure 4C serves this double purpose.

Frequency Compensation

As the frequency is varied the static measuring circuit can be kept in balance only by varying the voltage applied thereto in a predetermined fashion. As it is desired to regulate for the same generator voltage with some departure from normal frequency, it is necessary to introduce between the potential transformer and the measuring circuit an impedance which will produce the necessary voltage variation with frequency on the measuring circuit. Network synthesis studies developed the proper combination of inductances and capacitances for this purpose. As the inductance required was a series device, it was obtained simply by proportioning the sequence network to have this value of inductance as viewed from the output terminals.

Conclusions and Test Results

A static regulator was designed and built using the methods outlined in the paper. This regulator, whose circuit is shown in Figures 4A and C was designed for use with a Rototrol exciter and 1,500-kva generator. Tests have demonstrated it to be a highly satisfactory solution to the regulating problem outlined at the beginning of the paper.

The sensitivity was well within the design goal of plus or minus one per cent under steady or slowly changing load conditions. With the generator terminal voltages unbalanced due to the application of a single-phase load, the regulator maintained the average voltage within the sensitivity limits. For variations of frequency within reasonable limits, the regulator showed only small deviation from normal voltage.

Under sudden application of a 50 percent rated current load, at low power factor, the voltage dip[6] was only slightly in excess of the initial transient-reactance drop in the generator. The voltage returned to normal in less than one-half second. The action was smooth with very good damping.

Parallel-operation tests at rated power factor showed the automatic wattless

load division to be within six per cent of rated generator current up to full rating. This excellent paralleling was obtained with reactive-droop compensation of 5.5 per cent at full-load zero power factor, which is 3.3 per cent at full-load 0.8 power factor

Appendix I. Curve of E_f/E_R Versus E_x/E_R

With reference to Figure 6C, a curve of E_f/E_R versus E_x/E_R can be calculated, using θ as a parameter. E can be taken as 1, since ratios of voltages are to be determined and the actual values are immaterial. The steps in the computation are as follows:

1. Values of θ are taken from 0 to 90 degrees as the parameter.
2. Then E_x is equal to $E \sin\theta = \sin\theta$, and
3. E_d is equal to $E\cos\theta = \cos\theta$
4. The resistor branch is represented by an equivalent voltage, E_{eq}, and an equivalent internal resistance, R_{eq}, where

$$E_{eq} = \frac{R_f}{R+R_f} E = \frac{R_f}{R+R_f}$$

and

$$R_{eq} = \frac{RR_f}{R+R_f}$$

The total voltage across R_{eq} and R' is

$$E_R = E_d + E_{eq}$$

5. The ratio of E_x/E_R is then computed.
6. The field voltage, E_f, is a potentiometer fraction of E_R, minus E_{eq}. That is:

$$E_f = \frac{R_{eq}}{R'+R_{eq}} E_R - E_{eq}$$

7. The ratio E_f/E_R is then computed and plotted as a function of E_x/E_R.

Note that $\theta = 90$ degrees is the limit of performance, according to this theory, because, as shown in Figure 6C, the rectifier voltage, E_d, becomes zero at $\theta = 90$ degrees.

A sample calculation follows; the results are plotted in Figure 8 for the ratio $R_f/R = 0.3$.

Appendix II. Circulating-Current-Type Static-Network Field Input Power and Rectifier Voltages

With reference to Figure 6, and saturation curve, Figure 7, the steps in a power computation are as follows:

The field power P_f and voltage E_f are to be computed for a given departure of line voltage from normal, and a given set of proportions R', R_f, and R. This calculation cannot be made directly. It is necessary to start with a given reactor voltage E_x, and calculate the field power and line voltage corresponding. After repeating for several values of E_x, curves of line voltage and field power can be drawn from which the field power can be read for the desired line voltage.

It is assumed that the network is so proportioned that the field voltage and power are zero at normal line voltage. This requires that at balance:

$R = \sqrt{(R')^2 + X^2}$, that is, equal impedances in the two branches up to the point of field connection. Thus, at balance the reactor voltage is slightly less than the line voltage. It is

$$E_{rn} = E_n \cos\sin^{-1}(R'/R)$$

where the subscript. n, denotes the value of a quantity at the normal balanced condition or

$$E_n = E_{rn}/\cos\sin^{-1}(R'/R)$$

In other words, if the reactor voltage is taken as unity at the balance point, the normal line voltage, E_n, is slightly over unity as given by the foregoing equation.

Procedure

The steps of procedure are then as follows:

The basis is stated; that is, R' and R_f in terms of R from which

$$R_{eq} = \frac{RR_f}{R+R_f}, \text{ and } (R'+R_{eq})$$

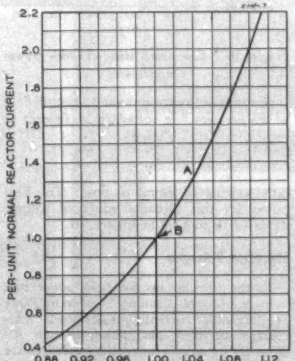


Figure 7. Typical saturation curve of saturating reactor

$$I_x = 2\left(\frac{E_x - 1.0}{0.10}\right)$$

A—Current doubles for every ten-per-cent increase in voltage

B—Balance point or normal operating point

are determined. The coefficients in the equation for E in terms of E_R and E_f are then determined.

$$E = E_R \frac{R}{(R_{eq}+R')} - E_f \frac{R}{R_{eq}}$$

The normal line voltage is calculated from the normal reactor operating point voltage as follows:

$E_n = E_{rn}/\cos\sin(R'/R)$

where $E_{rn} = 1.0$.

And finally the normal network power is calculated from

$$P_n = E_n I_{rn} \frac{R'+R}{R}, \text{ where } I_{rn} = 1.0$$

The steps in the calculations are as follows, item numbers being the same as the column numbers in the example, Table II.

1. A value of E_x is selected.
2. The corresponding current, I_x, is determined from the saturation curve (see Figure 7).
3. This current flows through the resistance $(R'+R_{eq})$ in series and produces the voltage drop E_R, where, $E_R = I_x(R'+R_{eq})$.
4. From this value of E_R, the ratio E_x/E_R is calculated.
5. The ratio E_f/E_R is determined from a curve obtained as described in Appendix I and shown in Figure 8.
6. The field voltage then can be calculated as follows:

$E_f = E_R(E_f/E_R) =$ Item 3 × item 5

7. E is then calculated as follows: From Figure 6, it can be seen that E_{eq} equals the voltage on R_{eq} minus E_f.

Since

$$E_{eq} = \frac{R_f}{(R+R_f)} E$$

this may be written

$$\frac{R_f}{(R+R_f)} E = \frac{R_{eq}}{(R'+R_{eq})} E_R - E_f$$

but since

$$\frac{R_f}{R+R_f} = \frac{R_{eq}}{R}$$

$$E = \frac{R}{(R'+R_{eq})} E_R - \frac{R}{R_{eq}} E_f$$

8. The per-unit line voltage is then calculated, E/E_n.

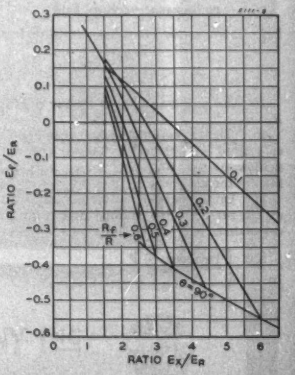
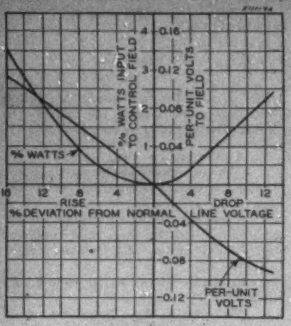


Figure 8. Curves of E_f/E_R versus E_x/E_R for use in computing power output of static regulating network

$R' = 0.20R$



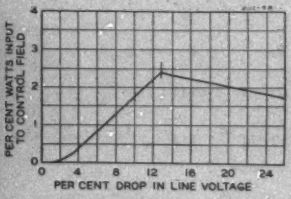
A. Normal range

$R'=0.20R$

$R_f=0.30R$

Per-cent watts are based on network watts at normal voltage

Per-unit field volts are based on average normal line volts



B. Extended range

$R'=0.20R$

$R_f=0.30R$

Per-cent watts are based on network watts at normal line voltage

Figure 9. Calculated static regulating circuit performance—control field

Input power versus line-voltage deviation from normal

9. The power consumed by the field is E_f^2/R_f.

10. The per-cent field power then can be calculated as $100P_f/P_n$. This is also the field watts per 100 watts drawn from the line by the network.

11. Or the network watts per field watt at ten-per-cent line voltage drop may be calculated,

$$\frac{100}{\text{Item 10}}\left[\frac{1-(\text{Item 8})}{0.1}\right]^2$$

This calculation should be made for the line voltage (column 8) corresponding most nearly to ten-per-cent voltage drop.

12. The field voltage in per unit of the average value of normal line voltage is given by E_f/E_n.

Table II gives a sample calculation by this method, the results of which are plotted in Figure 9A.

For drops in line voltage beyond the point at which the reactor rectifier goes to zero, the field power and voltage can be calculated setting E_d equal to zero. The field power for this extended range of voltage deviation is plotted in Figure 9B.

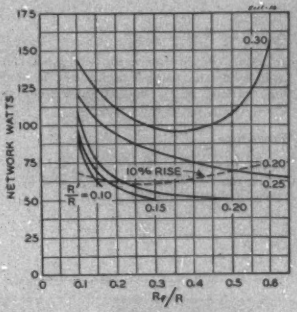


Figure 10. Calculated static-network power requirements

Network watts per watt input to control field at ten-per-cent line voltage drop (except as noted)

Rectifier Voltages

In the calculations for field power and voltage, of which a sample is given in Table II, the reactor current I_x is obtained. This current, rectified, also flows through R'. Thus the equations for rectifier voltages are

Reactor Rectifier—Refer to Figure 6C.

$$E_d=E_f+I_xR'$$

Resistor Rectifier

$$E_d'=-E_f+(I_x-I_f)(1-k)R$$

At line voltage = ten per cent from normal the rectifier voltages should be checked since the performance as calculated only holds true if the rectifier voltages are positive up to these limits, (or to whatever limits of operation the network is designed).

For example, if we refer to Table II, for $R'=0.2R=0.204$, and $R_f=0.3R=0.306$ at 90-per-cent line voltage, which is the point at which E_d is lowest, the reactor rectifier voltage is

$$E_d=E_f+I_xR'$$
$$=-0.0816+0.555\times0.306$$
$$=-0.0816+0.1698=+0.0882$$

This indicates that R' is sufficiently large and could be reduced somewhat. It must be remembered that harmonics have been neglected and that these calculations therefore must be used with considerable margin.

If it is desired only to ascertain that the reactor rectifier voltage is positive for a particular line voltage drop, no calculations are needed beyond those illustrated in Tables I and II. As long as the E_x/E_n value used in Table II corresponds to θ less than 90 per cent in Table I, the reactor rectifier voltage is positive, as explained previously. Thus it is convenient to stop the curves of Figure 6, prepared from calculations like Table I, at the boundary $\theta=90$ degrees. They cannot then be used beyond the proper operating limit.

The resistor rectifier voltage decreases as the line voltage drop increases to ten per cent. At ten-per-cent high (a point available in Table II) if the resistor rectifier voltage is just zero, then

$$E_d'=-E_f+(I_x-I_f)(1-k)R$$

$$0=-0.0739+\left(1.414-\frac{0.0739}{0.036}\right)(1-k)1.02$$

or

$$(1-k)=\frac{0.0739}{1.173\times1.02}=0.0617$$

that is, $(1-k)$ must be about 6.2 per cent in order that the resistor rectifier voltage remains positive up to ten-per-cent voltage increase.

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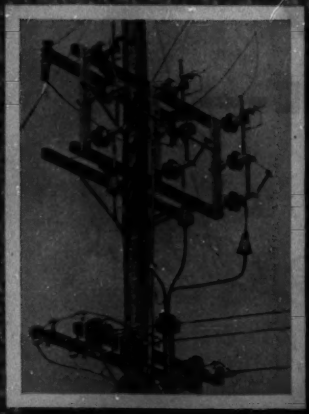

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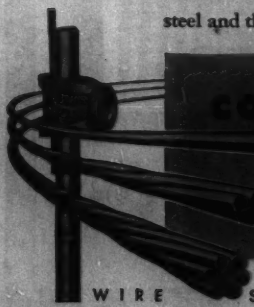

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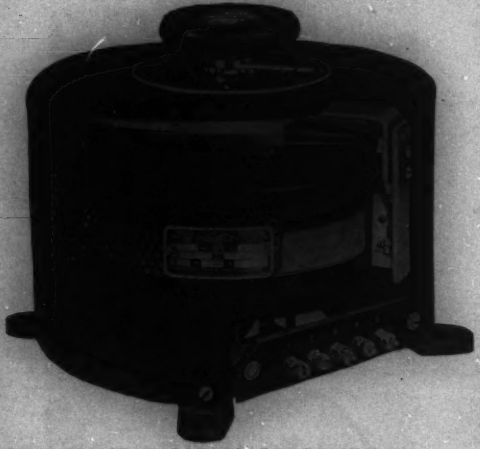

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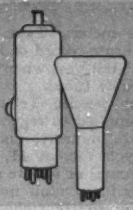

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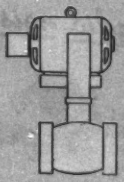
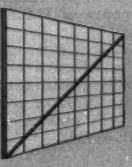


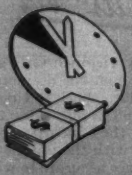
TEMPERATURE OR SPEED CONTROL

Electric furnaces, soldering apparatus or other electric heat-treating devices may be controlled smoothly and quickly by Transtat regulators. Voltage sensitive AC motors can be regulated to selected RPM—efficiently and economically with a Transtat.



SMOOTH COMMUTATION

The wide brush tract of evenly spaced segments separated by solid insulation provides an ideal commutating surface.



HIGH EFFICIENCY

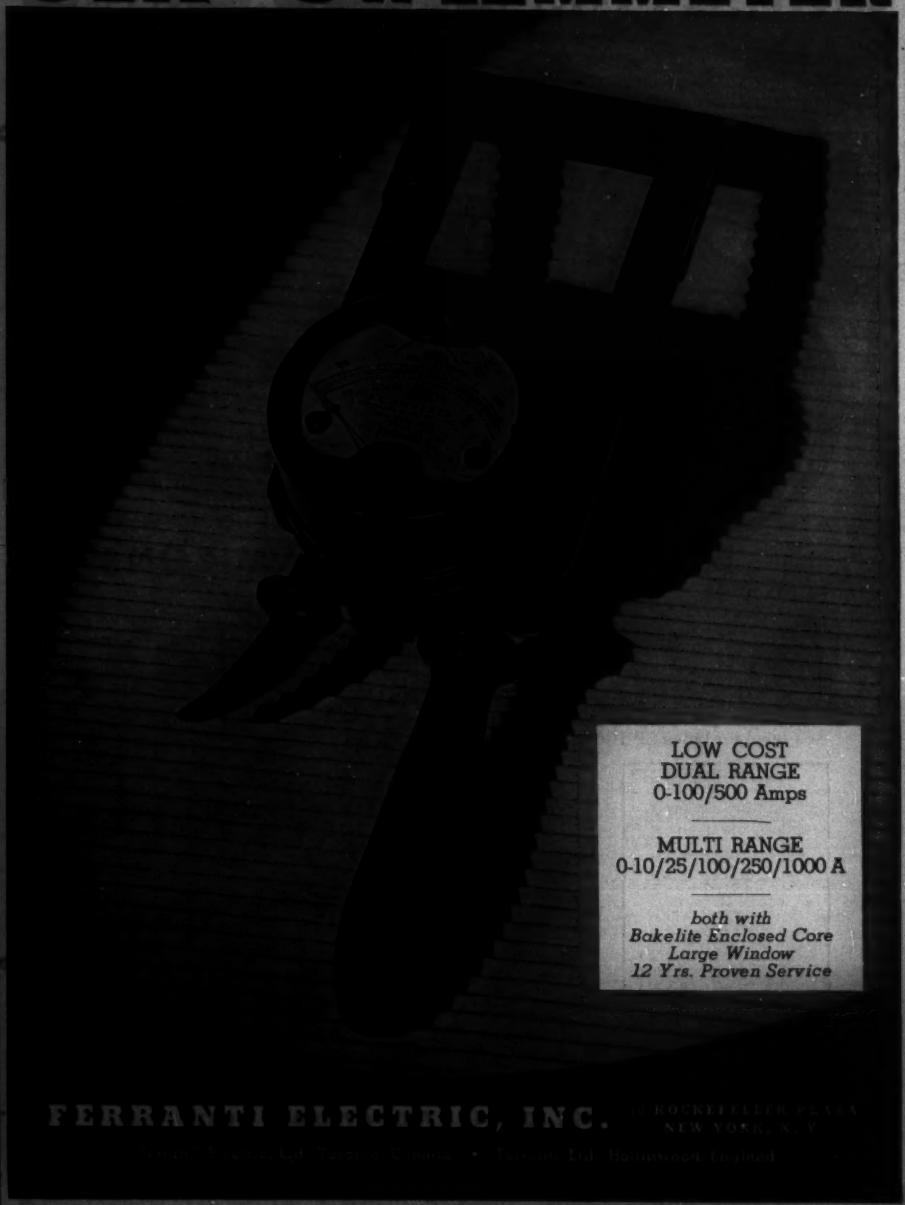
Transtats' transformer efficiency costs less in the long run than resistive control. High dimensional uniformity, flexible mounting speed assembly.

AMERTRAN

MANUFACTURING CORPORATION

Pioneer Manufacturers of Transformers, Reactors and Rectifiers for Electronics and Power Transmission

CLIP-ON AMMETER



FERRANTI ELECTRIC, INC.

HIGH VOLTAGE Ceramic Condensers

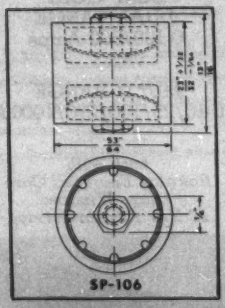
ERIE DOUBLE CUP CERAMICONS

REG. U. S. PAT. OFF.

FOR HIGH FREQUENCY USE

These compact, high voltage condensers are designed to carry appreciable amounts of current at high voltage without danger of corona or excessive internal heat. The silvered ceramic construction provides choice of temperature coefficient, excellent stability and retrace characteristics. Two sizes are illustrated above.

Type SP-106 is rated at 5 KVA. Peak working voltages at sea level for types SP-106 and SP-172 are as follows:

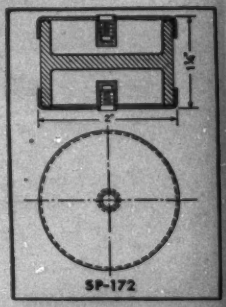


SP-106

Capacity	Temperature Coefficient	Peak Working Volts at Sea Level
20 MMF	NPO	10,000
30 MMF	NPO	6,500
39 MMF	NPO	5,000
51 MMF	N-750	10,000
75 MMF	N-750	7,500
100 MMF	N-750	5,500

SP-172

51 MMF	NPO	10,000
75 MMF	NPO	10,000
100 MMF	NPO	10,000
200 MMF	N-750	10,000
300 MMF	N-750	10,000
390 MMF	N-750	8,000



If you have applications for condensers of this style for either military or peacetime equipment, our engineers will be glad to discuss them with you.

Note: Test voltage, SP-106 and SP-172—60 cycle RMS equal to peak working voltage.

FOR HIGH ACHIEVEMENT IN WAR PRODUCTION

ERIE RESISTOR CORP., ERIE, PA.

LONDON, ENGLAND • • TORONTO, CANADA

• • • For More Than Indexes—Buy Erie Resistors • • •

3 OUTSTANDING FEATURES OF THE NEW EIMAC 4-125A TETRODE

LOW DRIVING POWER

With but 2.5 watts driving power, the 4-125A will deliver 375 watts output at frequencies as high as 120 Mc. The low driving power requirement has been achieved without the use of excessive secondary emission. The control grid is specially processed to reduce both primary and secondary emission.

HIGH FREQUENCY PERFORMANCE

The Eimac 4-125A will deliver 200 watts output at 250 Mc. The performance curves below show the relationship between driving power and power output at frequencies up to 250 Mc.

LOW GRID-PLATE CAPACITANCE

The grid-plate capacitance of the 4-125A is only *0.03 uufd.* This low value allows operation up to 100 Mc. without neutralization. Stability is further assured by the special grid processing which reduces secondary emission.

A technical bulletin on Eimac 4-125A Power Tetrode contains full specifications and detailed discussion of the tube's characteristics, circuit diagrams and constant current curves. Write for your copy today.

The Eimac 4-125A is the first of many new Eimac tubes that are on the way. Watch for future announcements.

ELECTRICAL CHARACTERISTICS

Filament: Thoriated Tungsten

Voltage	5.0 volts
Current	6.2 amperes

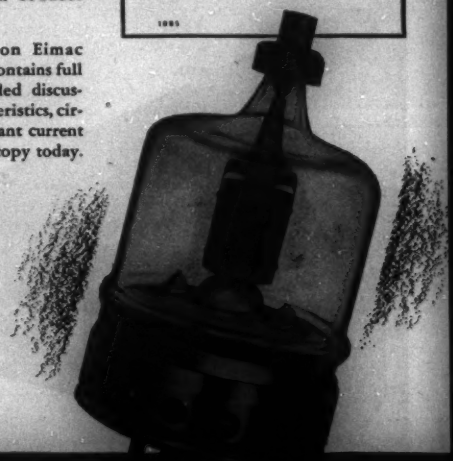
Plate Dissipation (Maximum) 125 watts

Direct Interelectrode Capacitances (Average)

Grid-Plate (Without shielding, base grounded)	0.03 uufd.
Input	10.3 uufd.
Output	3.0 uufd.

Transconductance (Ib = 50 ma., Eb = 2500 v., Esg = 400 v.) . 2450 umhos

1885



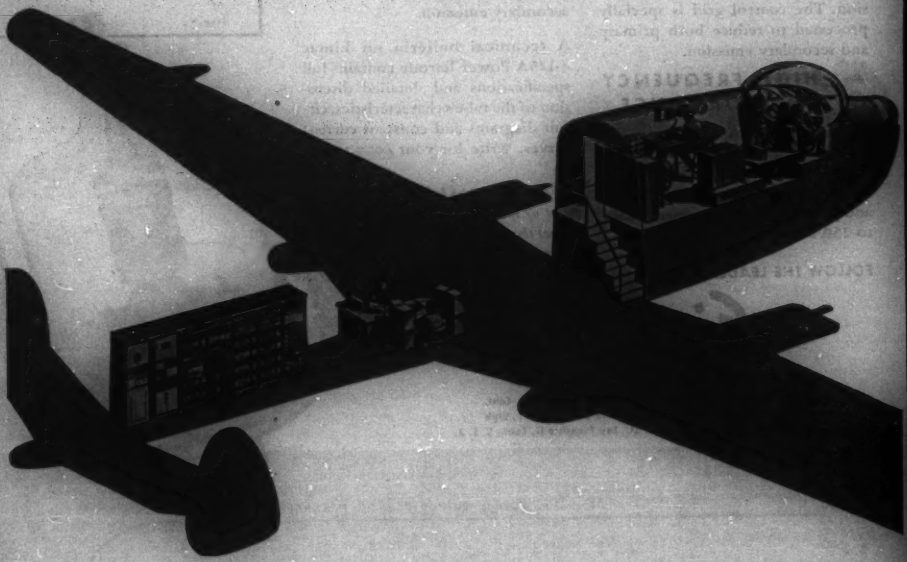
FOLLOW THE LEADERS TO

Eimac TUBES

REG. U. S. PAT. OFF.

EITEL-McCULLOUGH, Inc., 1085 San Mateo Avenue, San Bruno, Calif.
Plants located at: San Bruno, California and Salt Lake City, Utah
Export Agents: Frazar & Hansen, 301 Clay St., San Francisco 11, Calif., U. S. A.

THIS SEA-GULL LIVES ON THE GROUND



This is a "flight trainer"— an electronically operated replica of the PBM-3 flying boat. It was conceived by the Bureau of Aeronautics and developed by Bell Telephone Laboratories to train Navy bomber crews on the ground.

The new crew climb a few steps to get in and from then on it is like being in a big plane at night. Controls tug against the pilot's grasp and "engines" roar in response to the throttle. From his desk, the instructor creates every situation of real flight — even to iced-up wings, conked-out engines and sudden air-pockets. The novice pilot and his crew get the feel of danger without the hazard.

Once the control dials are set, the various effects are automatically organized and set in motion by concealed machinery which includes 200 vacuum tubes, 60 motors, loudspeakers and hundreds of associated parts. Twenty Laboratories engineers worked more than a year developing the project. Drawings covered an area equal to 15,000 square feet.

This is only one of the 1200 projects in which our experience has been able to help the Armed Forces. What we have learned in devising electronic circuits to train flyers will help build better telephones.

BELL TELEPHONE LABORATORIES

Exploring and inventing, devising and perfecting for the Armed Forces at war and for continued economies and improvements in telephone service

DO YOU NEED A CRYSTAL BALL?

THERE are times in the lives of all good engineers when a crystal ball would come in mighty handy. We know because we've had many a problem where it looked like aid from the occult was the only solution. Instead, we found that sound engineering plus the outstanding physical properties of Corning's electrical glasses usually supplied the answers.

These same glass qualities are ready to help you produce better postwar electronic products. Which do you need?

1. High dielectric strength—high resistivity—low power factor—wide range of dielectric constants—low losses at all frequencies.

2. Permanent hermetic seals against gas, oil and water between glass and metal or glass and glass.

3. Commercial fabrication to the fine tolerances of precision metal working.

4. Corning's metallizing process produces metal areas of fixed and exact specification, permanently bonded to glass.

* * *

Write us about your problems. We'd be interested in seeing if glass can help you. Address Electronic Sales Dept. N-8, Bulb and Tubing Division, Corning Glass Works, Corning, N. Y.

CORNING means Research in Glass

Electronic Glassware

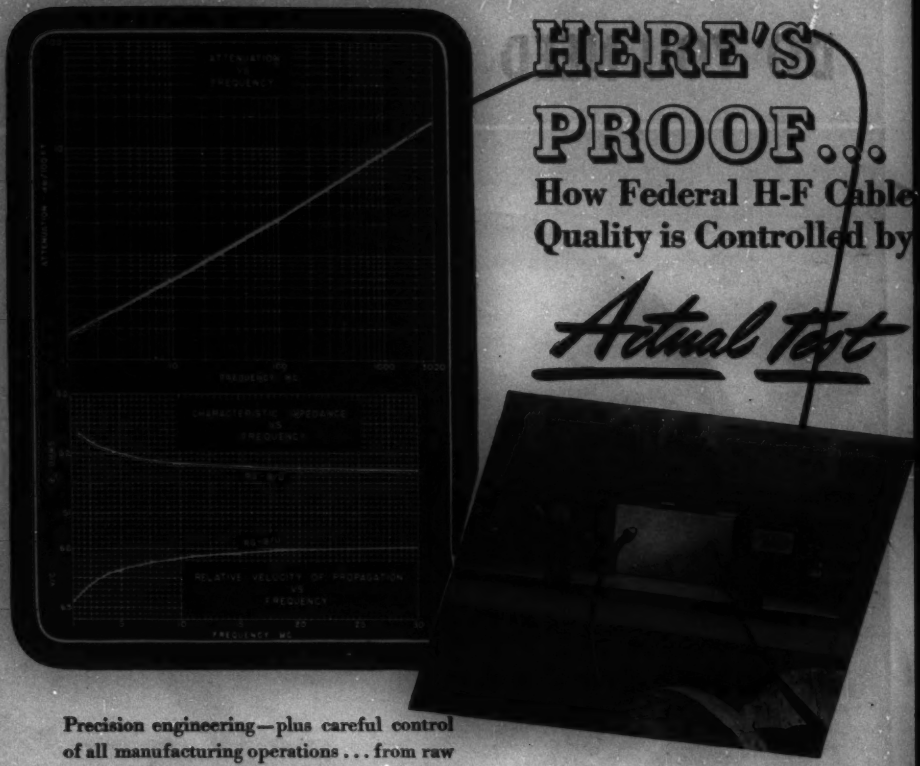
VYCOR CHARGE CORNING U.S. PAT. NOS. PYREX U.S. PAT. NO.

"PYREX", "VYCOR" and "CORNING" are registered trade-marks and indicate manufacture by Corning Glass Works, Corning, N. Y.

HERE'S PROOF...

How Federal H-F Cable Quality is Controlled by

Actual Test



Precision engineering—plus careful control of all manufacturing operations . . . from raw materials to finished product—mean complete reproducibility in any given Intelin Cable type . . . and overall superior cables.

Take Intelin RG-8/U for instance . . . general purpose "work-horse" of high-frequency cables. Its characteristics are shown in curves obtained—not from nominal design values—but from thousands of actual measurements on cable samples, with special equipment developed and used exclusively by Federal's Intelin Product Line.

Intelin's Attenuation Meter is an example of such equipment. It's a precision instrument . . . accurate to .1 db . . . developed by Intelin to provide a constant check on production quality and "measured" data for the equipment designer.

For additional information regarding Intelin RG-8/U . . . write *today* for Report E-53 —and for cable you can count on . . . *always* specify INTELIN.

FEDERAL TELEPHONE & RADIO CORP. FTR

Federal Telephone and Radio Corporation

There's a vast difference

between these Insulators

IT'S SOMETHING of a paradox with switch and bus insulators that a *new* one won't tell you much about an *old* one, but an *old* one will tell you a lot about a *new* one!

Tests on a new insulator indicate adherence to established standards of correct design, but they cannot predict the thing you want the most--reliability. Where do you find this? In the records of old installations.

When you buy station insulation today, you are protected by standards as far as such standards can possibly go, but to get that one thing you want the most, you must look back--far back--into the inherent "family traits" of a certain manufacturer.

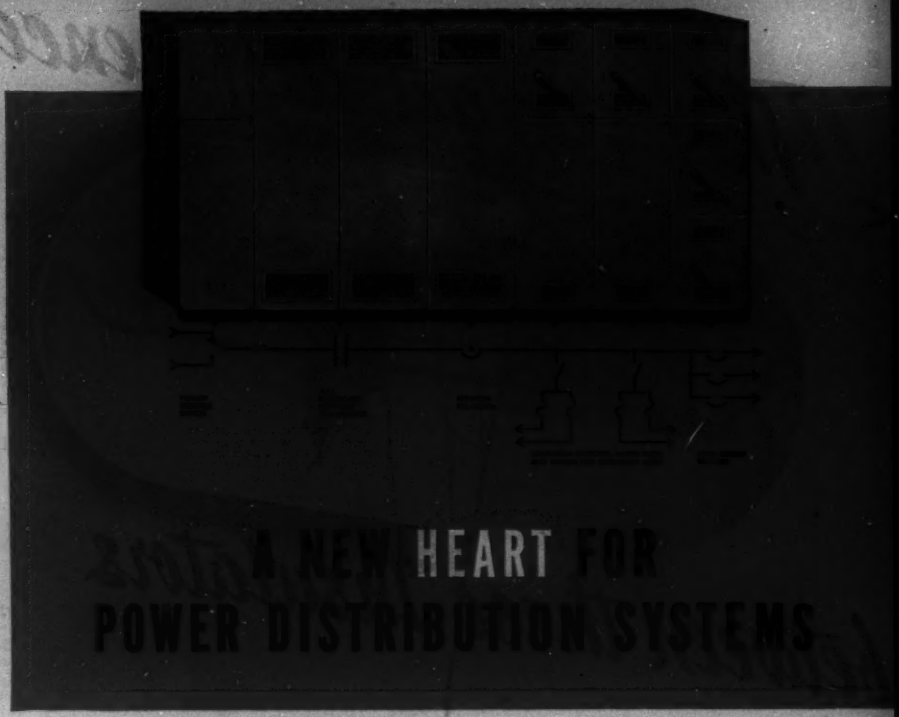
Do this with O-B. You will find 30-year-old O-B station insulators still on the job. You will find entire systems with nothing but O-B. You will find that most present O-B station insulators are bought on repeat orders, because of their sound performance.

When you buy new switch and bus insulators, look at the old ones. See the record *they* have established. This sensible approach will lead you to O-B.

Ohio Brass

MANSFIELD, OHIO

CANADIAN OHIO BRASS COMPANY, LIMITED.
NIAGARA FALLS, ONTARIO



A NEW HEART FOR POWER DISTRIBUTION SYSTEMS

ordered—installed—operated as a unit

Here is a new heart for power distribution systems —the *Westinghouse Network Unit.* It saves time in ordering, installation and operation. It eliminates piecemeal assembly on the job! It can be installed anywhere indoors without a vault—because it is completely air-cooled. It can be installed in the immediate vicinity of working personnel with complete safety, or it can be placed overhead to save valuable floor space.

This flexibility results in substantial savings in materials and labor, and in service interruptions, with consequent production losses. It permits location of the Network Unit at or near the centers of load.

The Westinghouse Air-cooled Network Unit is only one item of the complete equipment Westinghouse can supply. Others are: control centers, power centers, switches, breakers, capacitors, protective devices, switchgear—in fact, all the equipment needed for any power distribution system. By ordering from one supplier, you place responsibility in one place . . . save time in ordering, installation and co-ordination for operation.

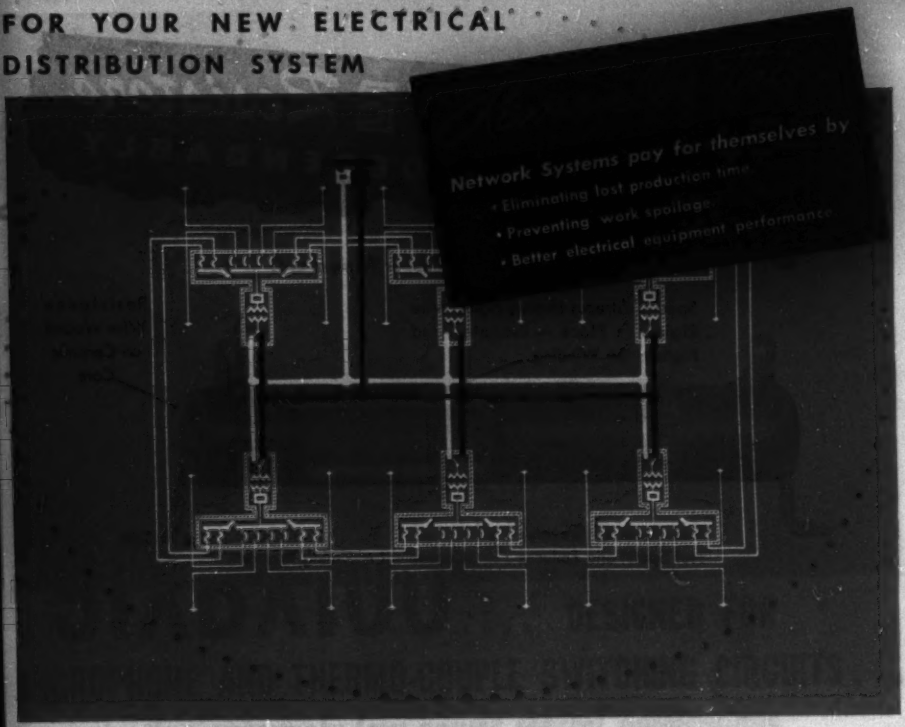
Complete specifications on all equipment are available to help you PLAN NOW for postwar construction. Phone your Westinghouse Office, or write Westinghouse Electric Corporation, P. O. Box 868, Pittsburgh 30, Pennsylvania. 3-94542A

Westinghouse

PLANTS IN 25 CITIES . . . OFFICES EVERYWHERE

INDUSTRIAL

FOR YOUR NEW ELECTRICAL DISTRIBUTION SYSTEM


Network Systems pay for themselves by
• Eliminating lost production time
• Preventing work spoilage
• Better electrical equipment performance

Since the first installation of Westinghouse industrial plant network systems (four years ago), we have been receiving comments like these:

- "because it assures uninterrupted service, we figure our network system has completely paid for itself by eliminating loss of production time caused by electric power interruptions."
- "light flicker has been entirely eliminated . . . improving working conditions and efficiency."
- "production has been increased because our motors are now getting the *right* voltage at *all* times . . . no longer any motor burnouts caused by undervoltage."
- "addition of new electrical facilities for critical work production was made in 50% less time . . . without disturbing any of the previous facilities."

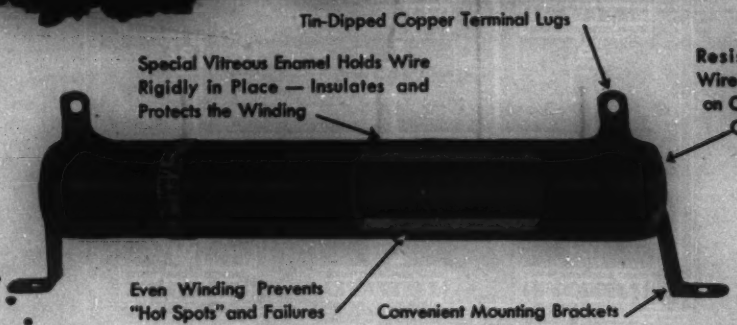
We sincerely believe that wherever the highest degree of flexibility—reliability—and voltage regulation are "musts", the Westinghouse network system is best suited for tomorrow's profitable production of peacetime goods.

However, Westinghouse supplies all types of electrical distribution systems, and will recommend the one best suited to your needs.

Call your Westinghouse representative today for advice and *practical* help in laying out your postwar distribution system. It pays to blueprint now for tomorrow's needs.

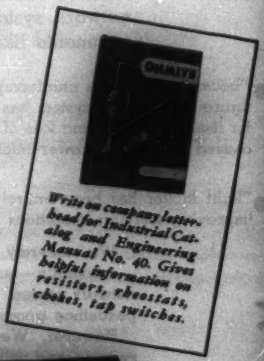
PLANT DISTRIBUTION SYSTEMS

Why OHMITE Resistors PERFORM SO DEPENDABLY


Tin-Dipped Copper Terminal Lugs
Special Vitreous Enamel Holds Wire Rigidly in Place — Insulates and Protects the Winding
Resistance Wire Wound on Ceramic Core
Even Winding Prevents "Hot Spots" and Failures
Convenient Mounting Brackets

Here you see a few of the important features that insure long life and trouble-free service in every Ohmite Resistor. In the lug type illustrated above, the resistance wire is both mechanically locked and brazed to copper terminal lugs to assure perfect electrical connection. Time-proved Ohmite vitreous enamel construction dissipates heat rapidly . . . withstands humidity. Today, Ohmite Resistors are extensively used in the Armed Forces, Industry, Communications, Research. *Made in a wide range of types and sizes* in stock and special units for every need. Consult Ohmite engineers on your resistor problem.

OHMITE MANUFACTURING COMPANY
4802 FLOURNOY ST., CHICAGO 44, U. S. A.


OHMITE
Write on company letterhead for Industrial Catalog and Engineering Manual No. 40. Gives helpful information on resistors, rheostats, chokes, tap switches.

Be Right with OHMITE
RHEOSTATS • RESISTORS • TAP SWITCHES

91XBX100 . . . . . DESIGNED FOR MICROPHONE AND THERMO-COUPLE SWITCHING CIRCUITS . . .

and other extremely low power control applications

The Struthers-Dunn a-c operated Type 91XBX100 Relay has double-pole double-throw, make-before-break contacts that are especially designed for handling milli-volt, milli-ampere, and milli-watt loads. Each moving contact consists of six laminations. The long sliding motion of the six contact surfaces results in extremely low and constant contact resistance, thus assuring electrically smooth performance—a "must" in audio frequency or recording instrument switching circuits.

The metal mounting plate acts as a shield, isolating the magnetic structure from the contacts, minimizing the possibility of induced a-c hum in the contact circuits.

Operating coils are available for use on standard voltages up to 230 volts a-c, 60 cycles.

DISTRICT ENGINEERING OFFICES IN THESE CITIES TO SERVE YOU:

ATLANTA • BALTIMORE • BOSTON • BUFFALO • CHICAGO • CINCINNATI • CLEVELAND • DALLAS • DENVER • DETROIT • HARTFORD • INDIANAPOLIS • LOS ANGELES • MINNEAPOLIS • MONTREAL • NEW YORK • PITTSBURGH • ST. LOUIS • SAN FRANCISCO • SEATTLE SYRACUSE • TORONTO

STRUTHERS-DUNN, Inc., 1321 Arch Street, Philadelphia 7, Pa.

STRUTHERS-DUNN

5,312 RELAY TYPES

Is your power system suffering

Newly designed equipment and experienced operators apply these improved tapes to the cable insuring proper tension, correct angle of application and proper control of tape position.

Heat test. Precisely controlled ovens subject varnished cambric to aging tests far in excess of normal requirements.

Corona discharge eliminated by conducting rubber. Left—cable insulated with ordinary rubber; note corona. Right—same cable protected by conducting rubber—no corona.

A. VARNISHED CAMBRIC INSULATED LEAD-SHEATHED CABLE with Type PS Shielding. Note use of two semi-conducting tapes—one over the insulation and one between conductor and insulation. PS Shielding prevents spark discharges and corona with attendant ozone formation between insulation and sheath.

B. THREE-CONDUCTOR VARNISHED CAMBRIC CABLE, belted construction with braided cover for dry locations.

Types of Varnished Cambric Cables

- Single-conductor series street lighting cables.
- Multiple-conductor non-leaded and unarmored cables.
- Control cables with combination of different colored braids.
- Single-conductor lead-sheathed cables.
- Single-conductor non-leaded cables.
- Multiple-conductor lead-sheathed or metallic-armored cables.

from *War Fatigue?*

Let these husky new Varnished Cambric Cables shoulder the heavy loads

SOME products have been greatly improved during the war. Among them are U·S·S American Varnished Cambric Cables. In many respects, the characteristics of varnished cambric insulation lie between those of rubber and impregnated paper.

The improved type of varnished cambric now employed by the American Steel & Wire Company is highly resistant to heat. It is recommended for operating temperatures up to 85°C. In this respect it is notably superior to rubber. For working voltages of 5000 or less, it may be safely operated at the same maximum temperatures usually recommended for paper insulation.

In dielectric strength, varnished cambric is superior to rubber but not equal to impregnated paper. Compared to rubber, thinner walls of varnished cambric insulation may be employed for a given voltage. Where space is at a premium, new varnished cambric cables, with greater current carrying capacity, can be installed in the *same* space occupied by the old cables.

Cables with varnished cambric insulation are easier to handle and simpler to install than paper insulated cables—the high degree of skill and experience required for jointing and terminating paper cables is not required for varnished cambric cables.

The fact that oil and grease do not injure varnished cambric insulation is another important advantage that recommends it for many purposes. Varnished cambric has less moisture resistance than rubber; and for damp locations, it requires a waterproof covering such as a lead sheath.

For complete information on U·S·S American Varnished Cambric Cables, write for our new catalog.

American Steel & Wire Company

Cleveland, Chicago and New York

Columbia Steel Company, San Francisco, *Pacific Coast Distributors*

United States Steel Export Company, New York

UNITED STATES STEEL

Where American Varnished Cambric Cables offer definite advantages

IN MODERATE OR LOW VOLTAGE INSTALLATIONS where its superior heat resistance permits greater current carrying capacity for a given copper area.

IN POWER PLANTS for general wiring and such applications as insulated bus bars, motor and generator leads, connections for oil switches, transformers and voltage regulators.

IN MANUFACTURING PLANTS, especially where heavy loads must be transmitted for short distances.

U·S·S American Varnished Cambric Cables

Another "First"!

25,000 volts accelerating potential on a cathode-ray tube...

DuMONT MULTI-BAND

TYPE 5RP CATHODE RAY TUBE

Cylindrical flat-face tube. Approximately the size of conventional 5-inch tubes. Deflection-plate leads brought out through neck instead of base. Shunt input capacities and cross-coupling effects reduced to minimum. Second anode and intensifier leads brought out through envelope to facilitate high-voltage operation.

We repeat: 25,000 volts accelerating potential on a cathode-ray tube! That's front-page electronic news. Likewise cathode-ray history in the making.

The DuMont Multi-Band Tube (Type 5RP) permits recording at writing rates in excess of 2500 km/sec (using a 35 mm camera with f:1.9 lens) corresponding to sine wave transients at 40 megacycles!

This is a hot-cathode, permanently-sealed, high-vacuum tube. Subdivision of the intensifier element provides a controlled gradient allowing a total accelerating potential of 25,000 volts to be employed, with only slightly reduced deflection sensitivity. Greatly increased brightness with small spot size results in a writing rate far exceeding that heretofore obtainable.

Yes, DuMont pioneering continues.

Literature on request.

© ALLEN B. DUMONT LABORATORIES, INC.

DUMONT *Precision Electronics & Television*

ALLEN B. DUMONT LABORATORIES, INC. PASSAIC, NEW JERSEY • CABLE ADDRESS, WESPEXLIN, NEW YORK

The basic starting point in designing transportation communications equipment is CONSTANT VOLTAGE

With a calculated operating voltage, communications equipment can be designed to operate superbly in the laboratory.

But what happens when this equipment gets into the field where voltages may vary as much as 30% from the laboratory standard? Signals become indistinct and garbled and the life of costly tubes may be prematurely shortened.

The communications equipment now being designed to provide greater safety, greater efficiency in the operation of our rail, sea, air, bus and truck transportation cannot fulfill this function if it is to rely on uncertain supply voltages. Constant voltage here is a "must".

SOLA Constant Voltage Transformers specially designed for communications equipment have been widely and successfully used before and during this war. They are the starting point in the basic design of much of the equipment now being planned for the major developments that are coming. Have you planned them into your equipment?

Consultation *now* with SOLA engineers means better communications for the future. SOLA Constant Voltage Transformers are available in standard designs in capacities from 10VA to 15KVA. Or special units can be designed to meet any requirements. SOLA Constant Voltage Transformers require no supervision or manual adjustments. No networks or moving parts to get out of order. They protect both themselves and the equipment against short circuit. They are a practical and economical solution to ever present voltage problems.

SOLA
Constant Voltage Transformers

To Manufacturers:
Built-in voltage control guarantees the voltage called for on your label. Consult our engineers on details of design specifications.
Ask for Bulletin ACV-102

Transformers for: Constant Voltage • Cold Cathode Lighting • Mercury Lamps • Series Lighting • Fluorescent Lighting • X-Ray Equipment • Luminous Tube Signs Oil Burner Ignition • Radio • Power • Controls • Signal Systems • etc. SOLA ELECTRIC COMPANY, 2525 Clybourn Avenue, Chicago 14, Illinois

chemical analysis

means better materials and manufacturing processes

What have test tubes to do with capacitors?

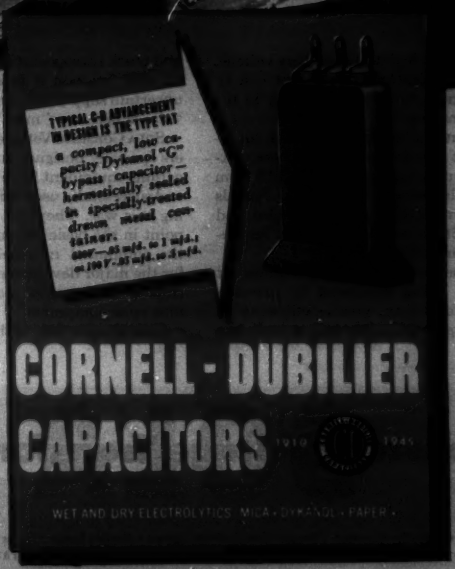
A great deal. Here in our laboratory, every process used in manufacturing Cornell-Dubilier capacitors comes under the patient, searching scrutiny of expert capacitor chemists.

The evidence must be positive. These specialists are meticulous people. They take nothing for granted. No detail is too insignificant, too commonplace to merit their closest attention.

They apply their research to practical purposes. Their tests and keen analysis insure better materials for making capacitors.

That is why more engineers specify C-D than any other make. If you have a capacitor problem, get the help of a specialist. Write to Cornell-Dubilier Electric Corporation, South Plainfield, New Jersey. Other plants: New Bedford, Brookline, Worcester, Mass., and Providence, R. I.

TYPICAL C-D ADVANCEMENT IN DESIGN IS THE TYPE TAT a compact, low capacity Dykanol "G" bypass capacitor — hermetically sealed in specially-treated drawn metal container.



CORNELL - DUBILIER CAPACITORS 1910 1945

WET AND DRY ELECTROLYTICS · MICA · DYKANOL · PAPER ·

NEW STACKPOLE SILVER-GRAPHITE *Contact Material*

LONGER LIFE...GREATLY IMPROVED CONTACT DROP

A NEW Stackpole development comes as the first *major* Silver-Graphite Contact advancement since Silver-Graphite Contacts were pioneered years ago by Stackpole and Westinghouse engineers in collaboration.

30% harder than conventional Silver-Graphite types, but with no change in the composition of its ingredients, this new Stackpole material greatly prolongs contact life under short circuit conditions, assures far better contact drop, and improves wearing qualities tremendously. Operating against a silver tungsten contact on an actual circuit breaker application, the material has proved its ability to withstand up to 13,000 amperes under short circuit conditions!

It is an ideal material for a wide variety of circuit breaker, contactor, and relay applications. Composition ranges from 3½% to 10% graphite to meet individual operating conditions, and the contacts can be produced in practically any required shapes or sizes.

STACKPOLE CARBON CO.
ST. MARY'S, PA.
EXPORT: Stackpole Carbon Co.
251 W. 19th St., New York 1, N. Y., U. S. A.

STACKPOLE

MOLDED METAL CONTACTS

Silver-graphite . . . Silver-copper-graphite . . . Gold-graphite . . . Silver-nickel . . . Silver-molybdenum
Silver-tungsten . . . Silver-nickel-molybdenum . . . Silver-nickel-tungsten and dozens of special alloys

Coup de Main: The battle royal or main bout, which immediately followed a general softening-up during knighthood forays.

Morganite

CARBON BRUSHES

MORGANITE BRUSH COMPANY, INC., LONG ISLAND CITY 1, N. Y.

1629 Telegraph Avenue, Oakland 12, California. Tel. - Glencourt 5838

433 South Spring Street, Los Angeles 13, California. Tel. - Michael 2834

Stratton Terminal Building, 9 South Clinton Street, Chicago 6, Illinois. Tel. - Randolph 2596

Looks as though new methods sometimes bust an old problem wide open!

We have an arsenal of new grades to try on your commutation problems—old or new. Why not try one?

Use MORGANITE and know you're right!

Why ALL SWITCH BASES SHOULD BE MADE OF *Porcelain*

Universal porcelain switch bases do not deteriorate under the high temperature of an arc or corona, which in many other types of insulator materials would cause loosening of contacts and connections. Porcelain insulation does not carbonize, therefore flash-over and consequent dielectric failure is eliminated. Porcelain dissipates generated heat quickly which in turn forces evaporation of moisture which might be absorbed in an insignificant amount in the porcelain base. Universal engineers invite you to submit your insulator problems.

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Foremost Manufacturers of Transformers to the ELECTRONIC INDUSTRY

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Should you have limited space requirements, this transformer (the smallest hermetically sealed unit now available) can be supplied to specifications.

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United Transformer Corp.

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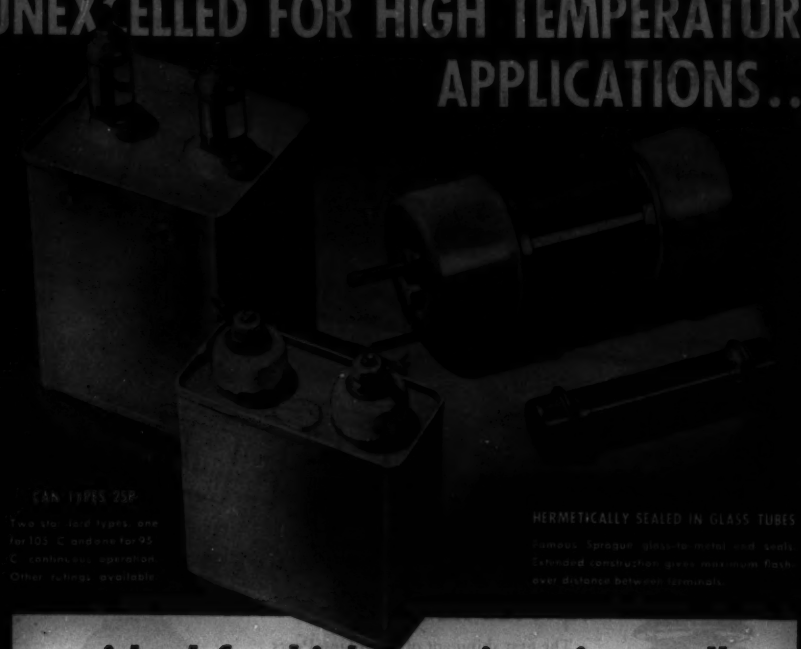

CAN TYPES 25P

Two sizes, axial types, one for 105° C. ambient for 95° C. continuous operation. Other ratings available.

HERMETICALLY SEALED IN GLASS TUBES

Famous Sprague glass-to-metal end seals. Extended construction gives maximum flashover distance between terminals.

...ideal for higher ratings in smaller sizes at lower temperatures

Sprague Capacitors impregnated with the exclusive VITAMIN Q impregnant make possible the use of much smaller units—with a substantial safety margin—on numerous high-voltage, high temperature applications ranging from transmitting to television. Where high temperature is not a factor, their unique characteristics assure materially higher capacity ratings for a given size.

Type 25 P VITAMIN Q Capacitors operate satisfactorily at thousands of volts at ambient temperature as high as 115° C. Insulation resistance at room temperature is *more than 20,000 megohms per microfarad.* Throughout the temperature range of +115° C. to—40° C. they retain all virtues of conventional oil-impregnated capacitors.

WRITE FOR NEW CATALOG

Sprague Catalog 20—just off press—brings you details on VITAMIN Q Capacitors in both can and glass tube types as well as dozens of other paper dielectric types for today's exacting uses.

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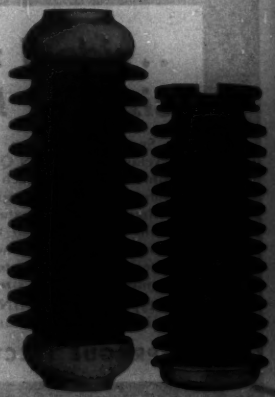
VITAMIN "Q" CAPACITORS

TRADE MARK REG. U. S. PAT. OFF.

LAPP LINE POSTS HAVE A 15-YEAR SERVICE RECORD

The first shipment of Lapp Line Posts went into service 15 years ago. The installation was the one which had inspired The Line Post design—a particularly bad, and previously unsolved, dirt condition. Since then, hundreds of thousands of Lapp Posts have gone up, in many cases a desperation answer to a difficult service problem—dirt condition, mechanical attack, radio noise, arcover failure. And the 15-year service record of these insulators shows them to stand up better, with fewer line outages, and lower replacement ratio, than any other insulator now in use.



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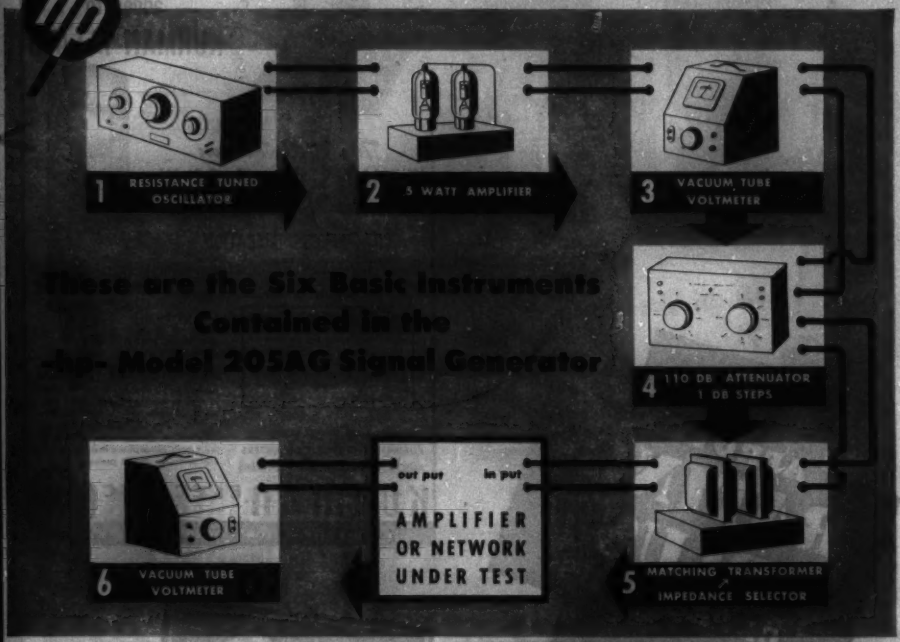
LABORATORY INSTRUMENTS FOR SPEED AND ACCURACY


1 RESISTANCE TUNED OSCILLATOR
2 5 WATT AMPLIFIER
3 VACUUM TUBE VOLTMETER
4 110 DB ATTENUATOR 1 DB STEPS
5 MATCHING TRANSFORMER IMPEDANCE SELECTOR
6 VACUUM TUBE VOLTMETER
out put
in put
AMPLIFIER OR NETWORK UNDER TEST

These are the Six Basic Instruments Contained in the -hp- Model 205AG Signal Generator

In order to reduce the task of making gain measurements to the most simple routine possible, *-hp-* engineers assemble all the necessary instruments into a single compact unit. To make amplifier gain measurements, it is necessary only that the operator connect input and output leads to the binding posts provided.

Any desired frequency within the range of 20 to 20,000 cps is made available by the resistance-tuned audio oscillator. Such frequencies are developed at any desired voltage between 150 volts and 50 micro-volts.

There are two vacuum tube voltmeters provided, one to measure input and the second to measure output. The input meter has a range of minus 5 db to plus 49 db, with an input impedance of 5000 ohms.

The output impedance can be instantly changed to the commonly used impedances of 50, 200, 500 and 5000 ohms which is very convenient for matching various types of networks. Furthermore, these impedances are balanced to ground and center tapped. The Model 205AG will supply 5 watts output with less than 1% distortion.

The *-hp-* Model 205AG, providing as it does the six basic instruments in a convenient unit, saves much valuable time in making audio frequency measurements. Its accuracy and versatility, coupled with the extreme ease with which measurements can be accomplished, make it an asset to any electronic laboratory or production line. Ask for more complete information. No obligation, of course.

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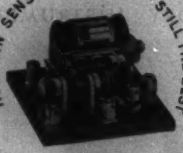
● Critical equipment designers, builders and users are insuring their assemblies with Aerovox rating-plus capacitors. That Aerovox extra-safety-factor is widely recognized today. Service records speak for themselves.

All Aerovox paper-capacitor voltage ratings are for standard temperature, pressure and humidity conditions, namely, 20° C., 30 inches of mercury (760 millimeters), and 50% relative humidity.

Where Aerovox capacitors are in hermetically-sealed cases, the only effect caused by changes in standard conditions will be the external flash-over voltage occurring at lower voltages for conditions involving reduced pressure and increased humidity. The capacitor proper remains unaffected. The maximum operating temperature for continuous operation at rated voltage is 65° C. ambient. If temperature is greater, operating voltage must be reduced. Derating data supplied on request.

AEROVOX *Capacitors*

"KURMAN SENSITIVE" OF 1930 STILL THE BEST



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The Well-Known

KURMAN SENSITIVE RELAY

the first to demonstrate the superior magnetic properties of hydrogen-annealed nickel alloy 15 years ago —again introduces an outstanding new feature—

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a thoroughly competent staff of Development and Design Engineers, and complete manufacturing facilities are at your service when you submit your Relay problems to us.

For trouble-free operation in any climate and at any desired altitude,

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relays are available, either of plug-in type or equipped with solder lugs. Some of these relays take as little space as 2" x 1¼" dia., and have up to 10 amps current capacity due to the special atmosphere introduced into the container under pressure.

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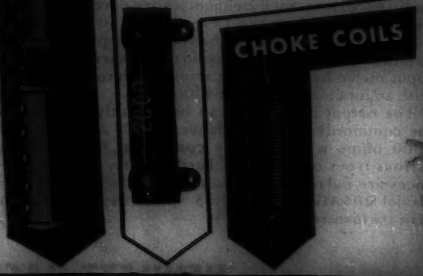

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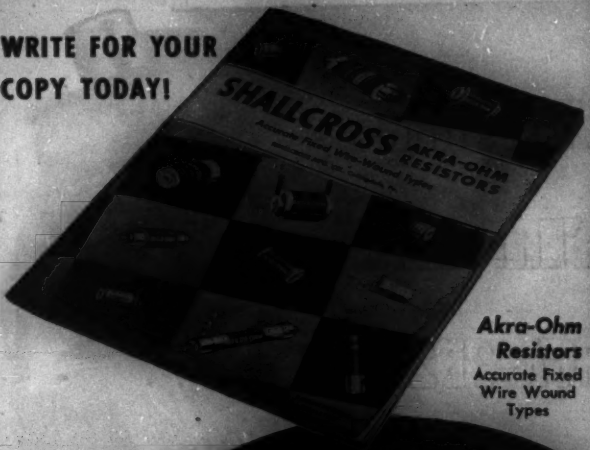

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ACCURATE FIXED WIRE WOUND RESISTORS

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Xenon-Filled Rectifier Tube Operates Efficiently Over 165°C Temperature Range

FOR applications in which ambient temperature varies widely, the 3B25 has important advantages over mercury-vapor-type tubes. No temperature-control devices are required, arc-back is minimized, and the tube drop remains constant at approximately 10 volts over the entire temperature range from −75°C to +90°C.

The RCA-3B25 also will carry higher currents than high-vacuum tubes of the same size — and with much lower tube drop.

The Xenon filling permits operation of the tube mounted in any position. Since the 3B25 is ruggedly constructed to withstand severe shock, it can be mounted near moving mechanisms without being adversely affected by vibration.

TECHNICAL DATA

In single-phase, full-wave operation, a pair of 3B25's will provide 1 ampere d-c output to the filter at 1270 volts. The tube is rated at 4500 peak inverse anode volts and an average anode current of 0.5 ampere.

General: Filament volts (a.c.), 2.5; filament current, 5.0 amperes; tube drop (approx.) 10 volts; overall length, 5⅛ inches ±7/16 inch; maximum diameter, 2 1/16 inches; cap, medium; base, medium 4-pin bayonet; mounts in any position.

Maximum Ratings (Absolute Values): Peak inverse anode volts (at 500 cycles or less), 4000; peak anode current, 2 amperes; average anode current, 0.5 ampere; surge anode current for maximum of 0.1 second, 20 amperes; ambient temperature range, −75°C to +90°C.

For more complete data, send for free data-sheet on RCA-3B25. Address: RADIO CORPORATION OF AMERICA, Commercial Engineering Section, Dept. 62-31A, Harrison, New Jersey.

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RADIO CORPORATION OF AMERICA

RCA VICTOR DIVISION • CAMDEN, NEW JERSEY

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These new friends of Laytex see this wire perform in freezing weather, in moist jungle heat,—and under the shock and impact of battle. No wire was ever meant to withstand such tough wear, yet Laytex comes through again and again.

Laytex Wires and Cables are at present supplying only military needs. One day Laytex will again be ready to fill a long list of civilian needs...Buildings, Police and Fire Alarms, Communications, Signalling, Power, Control, and many more.

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36 Models to choose from, for every insulating resistance problem in power fields, industry, marine services, laboratories.

Model 201 General Duty Vibrotest Range 0-200 megohms at 500 volts potential, 0-2000 ohms, 150-300-600 volts, AC or DC.

No tiresome cranking. No leveling. Easily read scale shows ohms and megohms. Compact, portable, versatile, handsomely and ruggedly encased. Long-lived trouble-free, thoroughly dependable.

Send for fully illustrated descriptive bulletins. Ask about new Model 238, calibrated 0-20,000 megohms direct reading.

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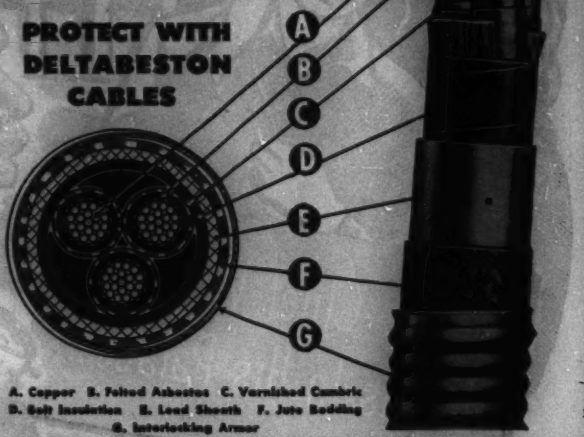


A. Copper B. Felted Asbestos C. Varnished Cambric
D. Belt Insulation E. Lead Sheath F. Jute Bedding
G. Interlocking Armor

One of the safest ways to insure steady performance in circuits that run around boiler rooms, steam tunnels, furnaces and other severe operating places is to protect with G-E Deltabeston Asbestos-insulated Cables. Unexpected cable failures in power, lighting or control circuits can make your plant lose production and profits. Why take unnecessary risks? Make an inspection trip around your power plant, check the torrid zones where heat, moisture and corrosive vapors are busy at their destructive work and rewire with Deltabeston Asbestos-insulated Cables.

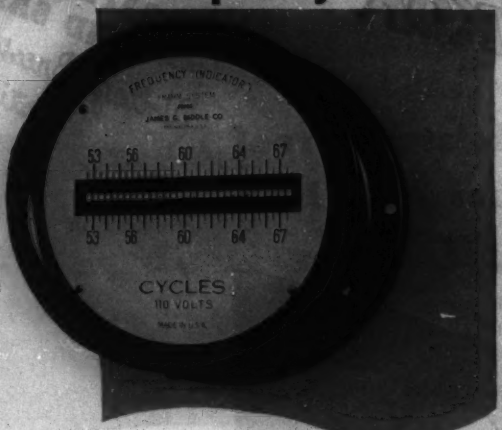
The Deltabeston product shown here is a three-conductor power cable with lead sheath, jute bedding and interlocking armor. It was designed for a central station to handle high current densities, during peak load periods. It has fine resistance to high ambient temperatures. It's flame-proof and physically tough. The armor takes the place of rigid conduit and gives the cable the same protection. Construction without interlocking armor or jute bedding can be supplied. Also available with asbestos braid instead of lead sheath. There's a Deltabeston Cable for every installation where heat, flame, moisture, oil, grease and corrosive vapors are a problem.

For additional information write to Section Y852-32, Appliance and Merchandise Dept., General Electric Co., Bridgeport, Conn. Deltabeston Cables are distributed nationally by Graybar Electric Co., G-E Supply Corp., and other G-E Merchandise Distributors.

Buy War Bonds and Keep Them

GENERAL ELECTRIC

"FRAHM" Frequency Meters



What are your Frequency Measuring Requirements ...25...60...100...400.....1400 cps?

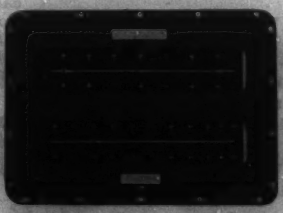
Frahm Frequency Meters in switchboard, miniature and portable types are regularly available for ranges between 15 and 500 cycles per second.

To meet special requirements, our laboratory has designed and built instruments for measuring frequencies as high as 1400 cycles. Such, we find, is possible by means of the same simple and direct resonant reed principle, usually requiring less than 0.1 volt-ampere power input, and without recourse to intermediate frequency conversion equipment. We believe that even higher frequencies are possible.

We invite correspondence regarding any frequency measurement problem in the audio and sub-audio range. For its solution we proffer our instruments, our services and facilities. In our 30 years of association with the resonant reed principle as applied to the measurement of frequency, we have been instrumental in the solution of a surprising variety of problems.

Write for Bulletin 1770-EE now in preparation.

This instrument was developed for direct indication of frequencies in the lower audio range and for simultaneous direct indication of harmonic components. Called a Harmonic Analyzer, it has unusual electrical characteristics and a wide range, with a total of 288 reeds.



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MATTHEWS WIRE REEL

a reel at low cost

Catalog 17-A Matthews Wire Reel is an inexpensive yet efficient tool for paying out or taking up wire. It is of sturdy construction and can be used for heavy as well as light work. The frame and cross members of turn table are of durable white oak and base, flange and coil arms are of cast malleable iron. Turn table revolves very easily with full coil of wire. Coil arms can be adjusted for coils of wire having inside diameters of 12, 18 and 24 inches. Complete reel finished in olive drab enamel. Base casting and turn table only, can be furnished for truck mounting or store room installation. Frame 70″ long x 24″ wide, overall height 19″, diameter of turn table 42″.

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All instruments are hermetically sealed and both vacuum and pressure tested under water. Case fabricated of pressed steel and made corrosion resistant to meet specifications. Terminals are a special glass soldered-in type.

All meters are fully shielded, permitting use on either magnetic or non-magnetic panels. Operation is accurate and dependable even up to 85° centigrade. Internal pivot construction in D.C. types assures longer life and greater resistance to shock and vibration. Write for further information today.

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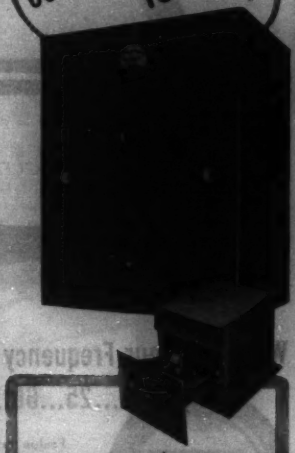
PRECISION CALIBRATED . . . LASTING ACCURACY

SAFE AND SANE Voltage Breakdown Testing



- Range: Model P-3 here shown, 0–10,000 v. D.C., 0–8,000 v. A.C. Model P-1, smaller, sloping panel, 0–4,000 v. D.C. P-2 has added 3,000 v. A.C. outlet.
- Continuously variable voltage over entire range.
- Operates directly from 110–130 v. 50/60 cycle A.C. line. Panel light indicates "On."
- Breakdown indicated by red signal light. Built-in meter indicates direct-reading voltage.
- Uniform maximum current 5 milliamperes on P-1, 50 milliamperes on P-3 over entire voltage range.
- Fine-grained crackled-enamel metal cabinet, 15" x 21" x 26" H.

• Simple, positive, safe and quick means of testing voltage break down of materials or components. Safety switch makes power supply inoperative if chassis is removed from cabinet. To speed up production testing, with absolute safety, drawer-switch test fixtures are available. Typically an "Industrial Instrument."

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Simplex was among the first to use X-ray inspections as an aid in the design of electric cables and as a check on manufacturing processes. The first installation in 1939 was so successful that a second outfit was added in 1942 and a third in 1944. All three are now helping to maintain Simplex quality.

Simplex Wire & Cable Co., 79 Sidney Street, Cambridge 39, Mass.

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Important war work now with large post war projects to follow.
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In applying for positions advertised by the Service, the applicant agrees, if actually placed in a position through the Service as a result of these advertisements, to pay a placement fee in accordance with the rates as listed by the Service. These rates have been established in order to maintain an efficient, non-profit personnel service and are available upon request. This also applies to registrants whose notices are placed in these columns.
All replies should be addressed to the key numbers indicated and mailed to the New York Office.

Men Available

RLRC ENGR; age 38; 3 yrs exper Chief Elec Engr for consulting engr. Six yrs pwr distr, 6 yrs communications engr and constr supt. Salary and location open. Partnership acceptable. E-109.

EXPER ELEC MAN, age 33; grad E. E., I.C.S. 1936; Assoc A.I.E.E. 1937; past 4 yrs chief electrician with large transportation concern; winding exper; desires oppor with util, engg firm or leading to electronic field; in southwestern U. S. or Latin America; speaks English and Spanish fluently. E-110.

RLEC ENGR; 24 yrs indus elec design, constr and maint. Eight yrs consulting office. Age 49; grad leading Univ desires permanent pos in engg office or large indus organization. E-111.

RLEC ENGR; E.E. and M.E.; married; 20 yrs exper design, constr, pwr plants, substations, distr systems, and indus plants; 5 yrs executive exper charge engg dept large util syndicate; 5 yrs purchase engg supt for foreign interest; languages, English, German, Russian, Armenian, Turkish; available immediately service design, constr, purchase. E-112.

ELEC-MECH ENGR, util and indus pwr station and distribution network practice, accustomed to repair of mech and elec machinery and apparatus in the field, desires pos as supt for util or indus pwr plant in the U.S. or South America. Thorough knowledge of French and Spanish. E-113.

Positions Available

DESIGNING ENGINEER AND DRAFTSMAN, electrical, for electric motor design. Excellent opportunity, postwar work. Location, Connecticut. W-4568.

ENGINEER, electrical, top notch, with experience in designing, developing, engineering and quality control of electrical appliances, primarily home appliance field. Must be a specialist on heating devices such as flatirons and toasters. Experience on fans, power tools, etc. desirable. Salary open. Location, Connecticut. W-5629.

ENGINEERS, 30–40, graduates of recognized engineering schools. Must have familiarity with electric utility property, a keen analytical mind, efficient job organization habits. Any experience in the following lines most helpful; rates, rate regulations, cost of service allocations, depreciation studies, etc. Permanent. Location, Ohio. W-5678.

ELECTRICAL ENGINEER, 25–35, graduate, with some experience in design and testing of various types of electrical equipment, particularly the magnetic type, to make a series of electrical studies and reports for a manufacturer in the Metropolitan Area. Salary open. W-5725(a).

POWER PLANT ENGINEER, 24–28, electrical graduate, with one or two years' experience in marine or stationary steam plant operation or having G.E. or Westinghouse Student training, for a 23,000 KVA generating station, steam and electric. Mechanical or electrical drafting experience desirable. Location, northern New Jersey. W-5730.

ASSISTANT ENGINEERS, electrical graduates, 30–50, experienced, for work on transmission and distribution systems and design of new facilities; public utility company experience desirable. Prior experience on general municipal electrical applications and miscellaneous industrial applications will also be desirable. Salary, $3600–$4200 a year, plus expenses and transportation when in field. Location, Louisiana. W-5751.

SALES ENGINEER to sell electrical switchboards, light and power panels, industrial controls and marine equipment to commercial, industrial, residential and marine trade. Must have a good electrical background, be familiar with the industry, have ability to analyze active markets and have a good working knowledge of switchboard construction. Write stating complete experience, age, salary required and references. Location, New York Metropolitan Area. W-5754.

SALES ENGINEERS, under 40 preferred, with electrical and mechanical backgrounds, to sell industrial storage batteries direct to utilities and industries. Salary, $4000 a year plus commission. Locations, New York City, Boston, Buffalo and Philadelphia. W-5758(a).

ENGINEERS, mechanical, electrical, civil, consulting engineering firm in New England. Permanent positions with good postwar opportunities. Statement of education, experience and salary expected should accompany application. F-681.

LAMINATED PRECIOUS METALS *for New* INDUSTRIAL USES

Laminated wire can be shaped for any industrial use, has application in many types of instruments and in any apparatus where corrosion must be prevented.

Typical uses include electrical contact strips, formed plated springs, low cost electric wire (silver-coated steel), radio electronic parts . . . where expansion must be held to a minimum (silver on invar) . . . or any project where electrical superiority, durability, or corrosion resistance is important.

Gold, silver, platinum and palladium or special precious metal alloys laminated to base metal have made these things possible . . .

- **The desirable electrical, mechanical or chemical qualities of the precious metals have been added to the strength or other desirable properties of base metals, precisely where and as required.**
- **Precious metal properties of corrosion resistance, electrical superiority, and durability are obtained without solid precious metal costs.**
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To assist you in the application of our products to your products we are maintaining a staff of thoroughly experienced metallurgists, chemists, designers and consultants . . . an up-to-date research and testing laboratory . . . and a splendidly equipped tool room. These are all at your service to cooperate with your own staff to the full extent of our facilities.

Your inquiries are cordially invited. Ask, too, for a copy of our new descriptive folder.

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FABRICATED PARTS AND ASSEMBLIES

D. E. MAKEPEACE COMPANY

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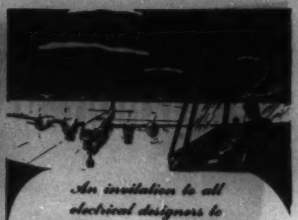

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GRAPHALLOY

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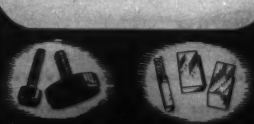
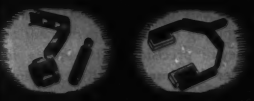
High current density, low contact drop, low electrical noise, and self-lubrication are characteristics of this silver-impregnated molded graphite that may be the answer to your electrical brush problems.

FOR CONTACTS

Low contact resistance and non-welding when breaking surge currents are inherent properties of this unique combination of conductive silver and self-lubricating graphite.



SLIP-RING AND COMMUTATOR



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Cannon Electric offers the widest range of electrical connectors in the field—literally thousands. To fit a connector to your requirements as accurately as possible, consult a Cannon engineering bulletin, our field engineering representatives, or the specialists of our engineering department.

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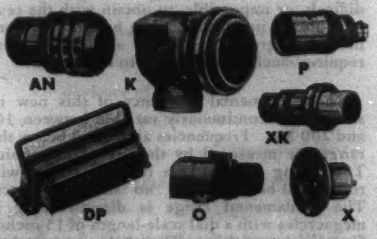

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For Measuring Frequencies Between 30 and 3,000 Mc

The new G-R Type 720-A Heterodyne Frequency Meter has all the operating conveniences of a broadcast-band type instrument, with a range of 30 to 3,000 Mc. Heterodyne methods offer several advantages over the conventional resonant type of meter. The fundamental frequency can be low enough to insure stability difficult, or impossible, to obtain with the resonant-circuit instrument. The heterodyne meter has much greater sensitivity and consequently requires much less r-f power to operate.

The fundamental frequency of this new instrument is continuously variable between 100 and 200 Mc. Frequencies above and below this range are measured by the use of harmonics. The tuning element is a butterfly circuit with rotor ball-bearings and no sliding contacts. The fundamental range is direct-reading in megacycles with a dial scale-length of 15 inches. One division of the auxiliary dial corresponds to a frequency change of 100 parts per million.

The built-in detector is a silicon crystal Type 1N21B. Usually no auxiliary pick-up is needed except when frequencies above 1,000 Mc are being measured it may be necessary to adjust the input antenna which is mounted on the front panel.

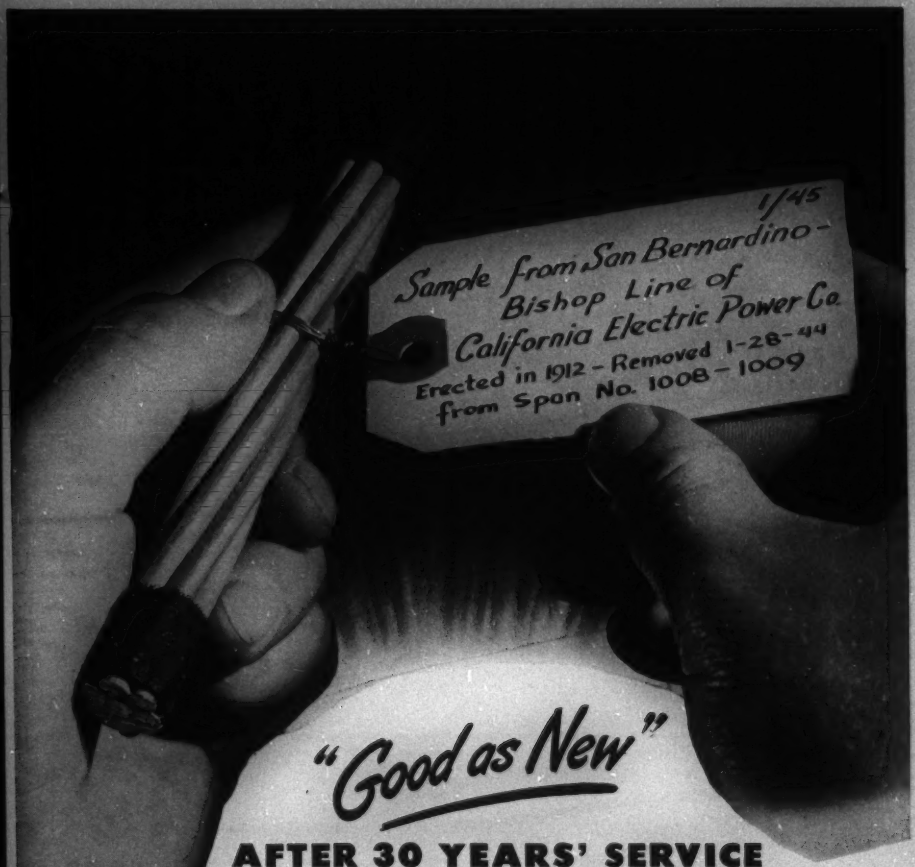
A three-stage amplifier is provided to produce indication on the panel meter when strong signals are received. Audible beats are simultaneously heard in the small speaker mounted behind the panel. A jack is provided for plugging in headphones for weak beat notes.

The complete instrument is self-contained. Its price, with batteries and spare crystal is $250.00. At present this meter is available only for top-priority war orders. Reservation orders for future delivery, however, are being accepted.

For complete information see the G-R EXPERIMENTER for July, 1945.

GENERAL RADIO COMPANY Cambridge 39, Massachusetts

90 West St., New York 6 920 S. Michigan Ave., Chicago 5 1000 N. Seward St., Los Angeles 38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A low flying bomber in California took down a span of A.C.S.R. line, which had been in continuous service for thirty years. Laboratory examination of this thirty-year-old cable resulted in the report "Good as new".

Dependability is an outstanding characteristic of Aluminum Cable Steel Reinforced. More than a million miles sold by Alcoa for rural and hi-lines are evidence of this fact.

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Use "Sealdtite" capacitors. Send for your copy of Catalog Y-4. *Any Climate—Any Atmosphere—Any Service.*

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